FLOOD RISK WHITE PAPER

Prepared for consideration by the Delta Stewardship Council

October 18, 2010

Not reviewed by or approved by the
Delta Stewardship Council

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Executive Summary

Those interested in the Delta and its future can rarely find common ground upon which to agree. The Delta has been controversial since its reclamation in the middle of the nineteenth century. Although the function and fabric of the Delta has changed considerably over the last 150 years, the controversy has remained a constant. Today's debate is based largely on the broad range of critical roles the Delta plays and how these roles can be better managed and balanced now and in the future. It is this very debate that creates the few points of reference on which most Delta stakeholders agree:

- **Levees create the current Delta.** Whether one lives in the Delta, counts on the water transported through it for drinking or irrigation, or has a favorite fishing hole there, it is relatively easy to agree that the very complexion of the Delta is formed by its levees. More than 1,115 miles of levees, creating approximately 65 islands or tracts, help protect approximately 700,000 acres of land within the legal limits of the Delta. Regardless of the authority under which they were constructed or who is responsible to maintain their condition, this collection of levees results in the Delta known today.
- **Levees in the Delta are at risk.** A long list of potential threats faced by Delta levees, and earthquakes, floods, subsidence, and sea-level rise are among the most notable. Each of these risks alone is cause for concern; however, together they represent a significant threat to the levees in the Delta and the people and property they protect. Each of these risks cannot be considered individually if an accurate understanding of levee risk is to be developed. The combination and/or coincidence of these risks must also be considered when developing a strategy to prioritize risk-reduction actions.
- **Business as usual will not be sustainable.** Many studies have been commissioned to evaluate how the levee system in the Delta functions, the current condition of these levees, and how likely they are to successfully resist the threats they face. While the numeric results of these studies are widely disputed, their underlying conclusions are consistent and widely accepted. The Delta as it is today is not sustainable, particularly if we continue to use current policies and commitments of resources. The number of levees in the system, their general condition, the practices used to maintain and rehabilitate them, and the level of investment are simply not adequate to counter the number, severity, and likelihood of risks they currently face.

Land reclamation through the construction of levees was one of the first forms of public improvement in California and was conducted extensively in the Delta. The original levees were constructed from loosely placed, random material obtained immediately adjacent to the levee footprint. This process of removing the land from the influence of tidal water dried the organic, or "peat," materials from the interior surface of the reclaimed island. This resulted in the oxidation of the organic material and subsequent land subsidence within the islands. Today, much of the central and western Delta is below sea level. With the interior elevation of some islands 12 to 15 feet below sea level, levees at least 20 to 25 feet high are required to hold back water on a daily basis. These islands in the central and western Delta are islands in name only—they are actually subsided bowls with the levees serving as the bowl rims.

The historic performance of levees in the Delta is poor. Moreover, the consequences of levee failures and the costs to restore the land protected by the levees have increased as the levee heights have increased. Many of the documented cases of levee failures in the Delta were attributed to high water during winter storm events; however, levees have also failed in the absence of any type of flood or earthquake. The most notable example is the June 2004 failure of the Upper Jones Tract levee, which led to the inundation of approximately half of Upper and Lower Jones Tracts. This levee failure occurred during a sunny day and reminded many of the vulnerability of the Delta levee system.

The true vulnerability of the Delta levee system is often lost within a labyrinth of myths, misinformation, and misunderstandings associated with levees in the Delta. In an attempt to establish a point of common understanding, the following frequently asked questions have been developed to summarize the contents of this document as well as to simply some of the commonly confused issues associated with these levees:

Question: What is the difference between a "project" and "non-project" levee?

There are approximately 1,115 miles of levees in the legal Delta and approximately 230 miles of levees in Suisun Marsh. Only about one-third of the levees in the Delta (385 miles) and none of the levees in Suisun Marsh are "project" levees. Project levees were authorized as part of a federal flood-control project and are eligible for rehabilitation by the U.S. Army Corps of Engineers (USACE) under Public Law 84-99. The Central Valley Flood Protection Board, formerly the Reclamation Board, serves as the non-federal partner to the USACE for all project levees in the Delta. All of the levees in Suisun Marsh and most Delta levees, about 730 miles, are non-project (or local) levees. These local levees are not usually eligible for rehabilitation by the USACE.

Question: Who owns the levees in the Delta?

Ownership of the levees in the Delta is often a mix. In some locations, the island's reclamation district, a local maintaining agency authorized under state lands, owns the levee. In other locations, the levee and the land it is founded on are privately owned, and the reclamation district usually has a permanent easement to the levee and a small area adjacent to it to conduct annual levee operations and maintenance activities. In the case of a project levee, this same permanent easement is held by the State of California as required by their assurances to the USACE. Project levee easements allow access to the levee by the USACE, State, and local maintaining agency.

Question: No levee failures have been attributed to earthquakes. Why worry?

It is correct that no levee failures in the Delta have been directly attributed to an earthquake. However, it is also true that no serious causative earthquake has occurred on a fault close enough to the Delta levee system in its "modern" form and configuration to test its resilience to liquefaction. Not experiencing a Delta levee failure caused by an earthquake should not reduce the level of concern. Levees and small dams similar to Delta levees have sustained serious damage and failure in many different earthquakes across the world. When a significant earthquake does occur, many of the Delta levees will likely be subject to dynamic loading within several minutes. If an earthquake is strong enough to cause the failure of one island, it is likely that other islands with the same or higher seismic vulnerability will also fail. Thus, earthquake-induced levee failures and the resulting inundation of multiple islands simultaneously is more likely than other risk types experienced to date in the Delta.

Question: Will sea-level rise affect Delta levees?

Yes. Observations at one of the oldest sea-level gauges on the West Coast, located at the Golden Gate Bridge, indicate a sea level increase of about 2 centimeters (0.79 inches) per decade during the 1900s. The CALFED Independent Science Board (ISB) reviewed and assessed the available science for use by Delta planning efforts such as Delta Vision. Given the inability of current physical models to accurately simulate historic and future sea level rise, they recommended considering a full-range of variability for sea-level rise from of 50 to 140 centimeters (20 to 55 inches) over the next 100 years. Even greater increases in sea level rise may result from melting ice sheets in Greenland and Antarctica. Using even the most modest (and observed) estimates for future sea-level rise, many Delta levees would require improvement to address the higher daily and flood event water surface elevations.

Question: Is subsidence still occurring?

Yes. Oxidation and other loss of peat is a widespread occurrence in the Delta and affects the surface elevation of the whole island. Areas which have organic (peat) soils are expected to continue subsiding as long as historic land management practices are not greatly altered. Subsidence rates are expected to decrease as the organic content percentage of the soil decreases. The duration of subsidence is dependent on the presence and thickness of the peat and organic deposits which are highly variable across the Delta.

Question: Is the Delta Risk Management Strategy analysis acceptable?

The initial Phase 1 Report of the Delta Risk Management Strategy (DRMS) was controversial and met with public criticism. However, many of the DRMS's results are similar to those in other investigations. Furthermore, the DRMS work was subjected to independent peer review through the CALFED Science Program. The executive summary of the final review conducted in 2008 states: "The CALFED Science Program's Independent Review Panel's (IRP) review of the revised DRMS Phase 1 Report concludes that the DRMS analysis is now appropriate for use in Phase 2, and is now acceptable for use as a tool for informing policymakers and others regarding potential resource allocations and strategies to address risk in the Delta…." The DRMS studies represent some of the most extensively peer-reviewed documents regarding future risks to the Delta.

Question: The Federal Emergency Management Agency (FEMA) and the USACE provided assistance to New Orleans after Hurricane Katrina. Would they assist the Delta after a levee disaster?

The areas inundated as a result of Hurricane Katrina in New Orleans were eligible for rehabilitation assistance from FEMA and the USACE. Many of the islands in the Delta are not eligible for rehabilitation assistance from either agency. First, only levees meeting certain criteria and accepted into the Public Law 84-99 program are eligible for federal rehabilitation funds and, for the most part, only the project levees are currently eligible (about one-third of all levees in the legal Delta). Second, eligibility for FEMA disaster grants or assistance following a levee failure is based on *all* of the levees protecting a given area (or island) meeting the Hazard Mitigation Planning (HMP) standard. Currently, very few areas (or islands) have all of their levees up to this standard.

The primary risk to the people, property, and State interests in the Delta results from the potential failure of levees that protect the land and define the water channels. Currently, these risks are inadequately mitigated by emergency preparedness, response, and recovery capacity relative to the potential frequency of a single levee failure scenario and/or the magnitude of a potential multiple levee failure scenario in the Delta.

Levee failures can occur during floods, earthquakes, and even undetected problems during normal conditions. Levee failures not only create direct damage and potential loss of life from flooding, but also change the configuration (water and land) of the Delta, and alter the mixing of fresh water with salt water. These temporary or long-term changes influence water supply, the ecosystem, and other Delta uses. Climate change is likely to compound the risk of levee failures resulting from increases in storm runoff to the Delta and from a rise in sea level that will place more pressure on Delta levees. Given the long list of potential threats faced by Delta levees, under current policies the Delta is not sustainable in its current form; risk must be reduced through a set of management policies that prioritize strategic and focused investments of resources into levees in a manner that best balances the multitude of uses in the Delta.

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Section 1 Introduction

The Sacramento–San Joaquin River Delta and Suisun Marsh, collectively referred to as the Delta, together comprise the largest estuary in the western United States. This region simultaneously serves a number of roles, all of which are integral to the size and sustainability of California and its economy. The Delta is home to numerous plant and animal species, some of which are found nowhere else in the world. The region serves as the hub of California's water supply system and as a thoroughfare for key transportation corridors and electrical, gas, and communication lines. The region is important to recreation and tourism, and its rich soils support a highly productive agricultural industry.

An extensive patchwork of levees delineates the waterways and islands that define the Delta. Unfortunately, these levees are constantly threatened by earthquakes, floods, subsidence, sea-level change, and other factors that could cause a catastrophic levee failure. Levee failures, and the associated inundation, can cause loss of life, destruction of property and infrastructure, interruption of water supply, crop loss, environmental damage, the interruption of commercial navigation, and other similar statewide economic impacts.

Land reclamation through the construction of levees was one of the first forms of public improvement in California and was conducted extensively in the Delta. The early focus on reclaiming "swamp and overflow" lands was granted to the State under the federal Arkansas Act of 1850. To help local landowners reclaim swamp and overflow lands, the State adopted a series of statutes authorizing them to form local reclamation districts. The area of a proposed district was outlined in a formation petition presented to a state or county board, which would order the district to be formed after a majority vote of the affected landowners.

A unique feature of the Delta is that much of its land is made up of highly organic soils, commonly referred to as "peat soils." Peat soils are very fertile and support an abundant agricultural harvest. Over time, agricultural practices have caused the land surface of Delta islands to subside. During the past century, subsidence has lowered the land surface of some Delta islands to as much as 25 feet below sea level. Land that is below sea level requires levees to act more like a dam and hold back water 365 days a year.

Levees

There are approximately 1,115 miles of levees protecting 700,000 acres of lowland in the Delta. In Suisun Marsh, there are approximately 230 miles of levees protecting over 50,000 acres of marsh land. Only about one-third of the levees in the Delta (385 miles) were authorized as part of a federal flood-control project. These levees, often referred to as project levees, are eligible for rehabilitation by the USACE under Public Law 84-99. All of the levees in Suisun Marsh and most Delta levees, over 730 miles, are non-project (or local) levees.

More than a century ago and without the benefit of modern engineering analysis and experience, many Delta levees Delta started out as 3- to 5-foot-high dikes of peat. Over time, the weight of the levees compressed and displaced the soft, organic soils beneath them; at the same time, the organic soils within the island interiors oxidized and were removed by wind, causing the land surface to subside significantly. Consequently, the levees must be continually raised and broadened, which often results in additional settlement and loss of freeboard. This process continues until the levees and their foundations stabilize. Many levee reaches have not yet stabilized. Delta levees today are now commonly 15 to 20 feet high and often protect island interiors that are 10 to 15 feet below sea level.

All of the levees in the Delta are operated and maintained by local agencies such as reclamation districts. Major rehabilitation and capital improvement projects for the Project levees are usually cost-shared among the federal, State, and local maintaining agencies. However, these same projects for the non-project (or local) levees have historically been financed primarily by the reclamation districts through assessment of the land owners protected by the levees. Because of the strategic importance of many Delta levees, during the late 1970 the State of California began to provide regular supplemental financing for levee maintenance, emergency response, and rehabilitation.

Risks

The vast network of Delta levees currently faces a multitude of risks, many of which are projected to increase in likelihood and magnitude in the coming decades. The four primary risk types covered by this white paper include (1) floods, (2) earthquakes, (3) continued subsidence, and (4) sea-level rise. Each of these risks can be evaluated independently; however, in reality they are acting concurrently and in combination on the levees in the Delta. For example, a section of levee is less likely to resist the 1 percent annual exceedance probability flood event (100-year flood) if the land behind the levee is decreasing in elevation due to subsidence and the elevation of the flood water is getting higher due to sea-level rise. This concept of aggregate or coincident risks makes the development of risk-reduction strategies in the Delta very complex but critically important.

In its simplest sense, the concept of risk can be represented by the following equation:

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$

In the Delta, probability represents the likelihood of a single- or multiple-levee failure scenario occurring in any given year. The consequence represents the outcome or impact associated with this levee failure or these levee failures. Using this model to define risk provides decision-makers with a means to communicate a broad range of risk scenarios involving one or more risk types as an “apples-to-apples” comparison.

Although not a comprehensive list, flooding, earthquakes, subsidence, and sea-level rise all pose a significant threat to levee integrity. In their current state and configuration, the Delta levees have not yet experienced a damaging earthquake; however, a major seismic event could affect the integrity of numerous levees across the Delta, potentially resulting in multiple simultaneous levee failures. If such an event were to occur during a time of low-to-moderate fresh water inflow from rivers and streams to the Delta, saline water would move upstream into the Delta from Suisun Bay. Delta waters would then become salty and could not be used for in-Delta irrigation, local urban supplies, or State and federal water project exports. Additionally, this saltwater intrusion would significantly impact the Delta’s aquatic ecosystem by disrupting and relocating the boundary between saltwater and freshwater.

Winter storm events causing high water surface elevations and high winds have been the most common cause of levee failures in the region. Although the likelihood of multiple levee failures caused by high water is less than from a major earthquake, the likelihood of a single failure occurring is higher based on the historical performance of these levees over the last century. High water in the Delta can overtop levees. It can also increase the hydrostatic pressure on levees and their foundations, causing instability and increasing the risk of failure due to through-levee and/or under-levee seepage. Most levee failures in the Delta have occurred during winter storms and related high-water conditions, often in conjunction with high tides and strong winds.

Purpose and Use

This Flood Risk White Paper has two primary purposes as it relates to introducing the topic of risk reduction to the Delta Stewardship Council in the course of developing the Delta Plan:

- The first purpose is to provide a historical context for levee construction and performance in the Delta.
- The second purpose is to introduce the primary types of risks facing the levees in the Delta today and how those risks may change in the future.

This White Paper will achieve these two purposes by briefly summarizing (1) the history of levee construction in the Delta, (2) levee performance over time, (3) the programs available to fund maintenance and rehabilitation, and (4) current risks and the future trends that affect levees' sustainability. This paper makes broad use of previous published studies. Emergency preparedness and response will be addressed in a separate white paper in development for November 2010.

Statutory Requirements

In November 2009, the California Legislature enacted SBX7 1 (Act), one of several bills passed related to water supply reliability, ecosystem health, and the Delta. The Act, which took effect on February 3, 2010, adds Division 35 to the Water Code—the Sacramento-San Joaquin Delta Reform Act of 2009 (Delta Reform Act—and creates the Delta Stewardship Council (Council) as an independent agency of the state. The Act charges the Council "to develop, adopt, and commence implementation of the Delta Plan...," a comprehensive management plan for the Delta, no later than January 1, 2012. The Act states the following goals for the State of California:

a. Achieve the two coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place.

b. Protect, maintain, and, where possible, enhance and restore the overall quality of the Delta environment, including, but not limited to, agriculture, wildlife habitat, and recreational activities.

c. Ensure orderly, balanced conservation and development of Delta land resources.

d. Improve flood protection by structural and nonstructural means to ensure an increased level of public health and safety.

These coequal goals are further expressed in the eight policy objectives set forth in the Delta Reform Act, which "the Legislature declares are inherent in the coequal goals for management of the Delta" (Water Code § 85020):

a. Manage the Delta's water and environmental resources and the water resources of the state over the long term.

b. Protect and enhance the unique cultural, recreational, and agricultural values of the California Delta as an evolving place.

c. Restore the Delta ecosystem, including its fisheries and wildlife, as the heart of a healthy estuary and wetland ecosystem.

d. Promote statewide water conservation, water use efficiency, and sustainable water use.

e. Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta.

f. Improve the water conveyance system and expand statewide water storage.

g. Reduce risks to people, property, and state interests in the Delta by effective emergency preparedness, appropriate land uses, and investments in flood protection.

h. Establish a new governance structure with the authority, responsibility, accountability, scientific support, and adequate and secure funding to achieve these objectives.

Finally, SBX7 1 also requires the following actions related to this objective as part of developing the Delta Plan:

a. Develop and implement a strategy to engage federal agencies (§ 85082) including building off the Interim Federal Action Plan for the California Bay-Delta (December 22, 2009), Section IV.B (pages 15 and 22-23).

b. Coordinate with and support DWR, in consultation with the U.S. Army Corps of Engineers (Corps) and the Central Valley Flood Protection Board, in preparation of a plan to coordinate flood and water supply operations of the SWP and CVP (§ 85309).

c. Section 85306 states, "The council, in consultation with the Central Valley Flood Protection Board, shall recommend in the Delta Plan priorities for state investments in levee operation, maintenance, and improvements in the Delta, including both levees that are a part of the State Plan of Flood Control and non-project levees."

Through the establishment of these goals, policy objectives, and potential early actions, the Act has placed focused emphasis on the importance of reducing risk. Aside from explicitly citing flood protection in both the goals and objectives, risk-reduction strategies are implicitly required to successfully address the other goals of improved water supply reliability, enhancement of the Delta ecosystem, and protection of the Delta as an evolving place.

Section 2
Background

The Delta is an important resource with a complex and sensitive environment providing numerous and critically important benefits. These benefits depend completely upon the continued viability of some system of levees protecting not only the subsided lands behind them, but also the water quality and habitats in the waterways. Today, almost 25 million people obtain at least some of their drinking water from water exports from the Delta, and these exports also support much of the State's agricultural and industrial economies. Even if an isolated water conveyance facility were developed and constructed to protect the State's water supply, the other coequal goal of restoring the Delta's ecosystem would remain dependent upon the integrity of the levee system. In fact, the Delta's agriculture, land-based ecologies, towns, critical infrastructure, and water quality and aquatic habitat would continue to require an intact levee system to maintain them. ***The Delta as an evolving place would not be without an evolving levee system.***

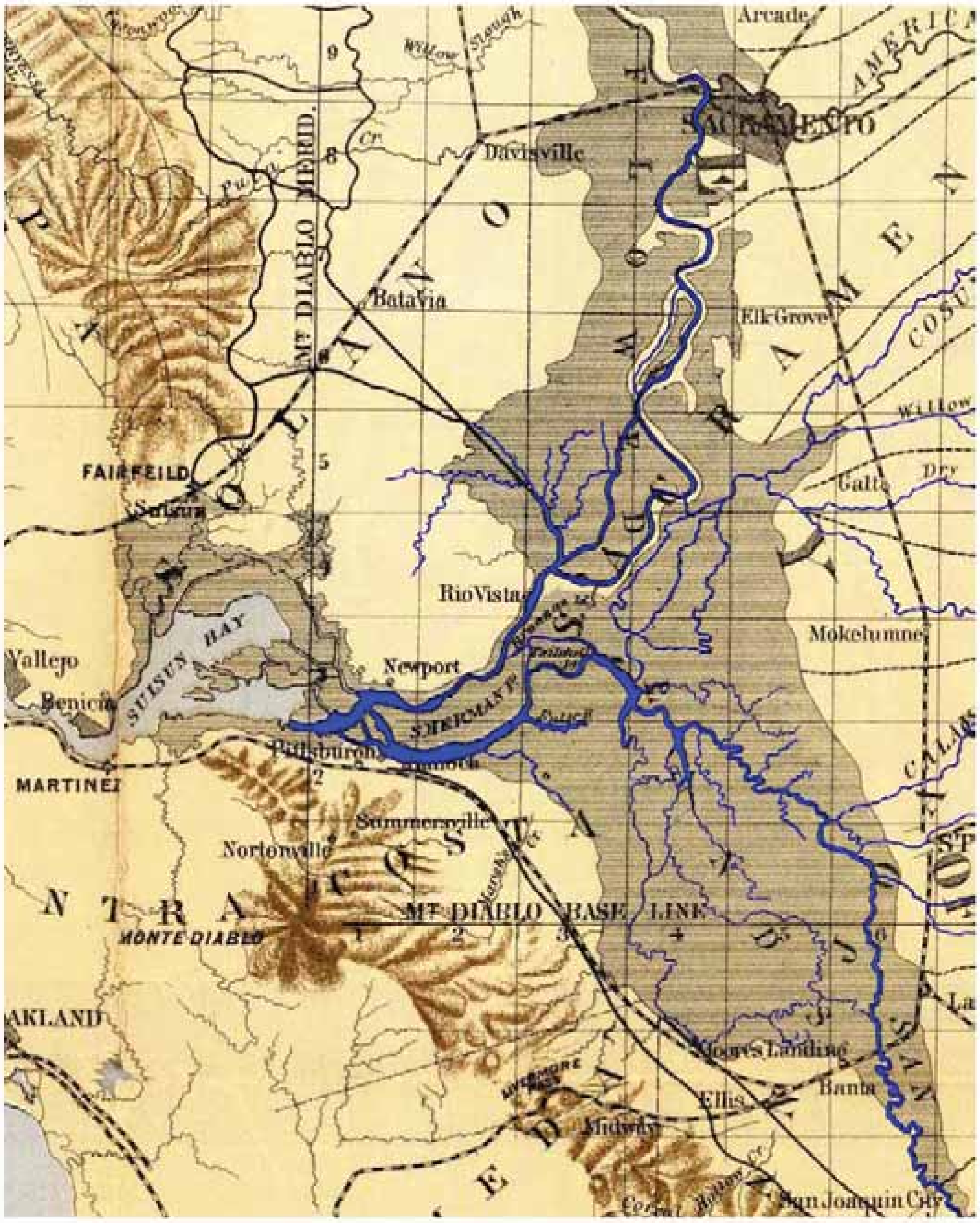
Pre-reclamation Delta

The historical Delta developed at the intersection of two overlapping geomorphic units, the Sacramento and San Joaquin river drainages. In the Delta, the interaction of fluctuating sea levels, tidal marsh, and peat formation, combined with the influx of alluvial sediments from river floods in the region, formed an inland "crow's-foot delta," consisting of distributary channels bordered by high natural levees surrounded by marsh plains, shown in Figure 2-1. Delta peats and organic soils began to form about 11,000 years ago during the last gradual rise in sea level. This rise in sea level created tule marshes that covered most of the central Delta. Peaty and other organic soils formed by repeated burial of the tules and other vegetation in the marsh (Shelmon and Begg, 1975; Atwater and Belknap, 1980; NHC, 2006; DWR, 2006; Jones & Stokes, 2007).

Early Reclamation Efforts

Reclamation of the Delta began in 1848 with the discovery of gold and the transport of people and supplies to the gold prospectors in the Sierra Nevada foothills. In 1850, the Swamp and Overflowed Lands Act was passed, ceding federal swamplands to the states to encourage reclamation. A few years later, the 1868 State Tideland Overflow and Reclamation Act enabled the creation of local reclamation districts, which led to the transfer of much of this public land into private ownership.

Figure 2-1
Historic (Pre-reclamation) Conditions in the Delta
Source: DWR, 2007



Most of the original levees used to reclaim wetlands in the Delta during the mid-1800s were less than 5 feet in height and were first constructed using human and animal labor. These small levees initially allowed the marshlands to be drained and farmed. Later, large steam-driven clamshell dredges were used to build and enlarge the levees to combat levee and land subsidence. Complicating these efforts were the disastrous effects of hydraulic mining. Beginning around 1853 and lasting approximately three decades, hydraulic mining washed vast amounts of material into the streams and canyons, resulting in reduced channel capacity downstream and increased flooding in the Sacramento Valley and the Delta. In 1893, the California Debris Commission was established. It had the combined tasks of regulating hydraulic mining, planning for improved navigation, deepening channels, protecting river banks, and affording relief from flood damages. The California Debris Commission began surveys of Sacramento Valley streams in July 1905 and developed a flood management plan in 1907. The plan included constructing and enlarging levees along rivers, creating bypasses to convey flows greater than the river's capacity, and dredging the Sacramento River to Suisun Bay. The California Debris Commission had an influential role in the history of flood management, but was terminated in 1986 with all of its responsibilities reassigned to the USACE (Denney, 1986; Kelley, 1998).

1850 Swamp and Overflowed Lands Act

In 1849, Congress granted to Louisiana certain wetlands described as "swamp and overflowed lands, which may be or are found unfit for cultivation" in order to facilitate land reclamation and the control of flooding. On September 28, 1850, Congress passed a subsequent Swamp and Overflowed Lands Act to convey similar public lands to twelve other states with no cost. This act, sometimes referred to the Arkansas Act, also applied to California. The only requirement of the act was that the states use the funds they realized from the sale of these lands to ensure that they would be drained, reclaimed, and put to productive agricultural uses. Any monies that the states received from the selling of this land to other interests were to be applied to the reclamation of the land and the development of agriculture. In 1860, Minnesota and Oregon were granted similar lands and benefits. In all, approximately 65 million acres of wetlands were transferred to 15 states. California received 2,192,506 acres of land: 549,540 acres in the Sacramento Valley were received, as were approximately 500,000 acres in the Delta.

1868 State Tideland Overflow and Reclamation Act

Between 1850 and 1868, California took different paths in deciding how to manage and develop the wetlands it had received from the federal government. In 1861, the State Legislature created the Board of Swamp and Overflowed Land Commissioners in an attempt to try to systematically manage reclamation projects. The Board's authorities were later transferred to the counties in 1866. In addition, land purchases were initially limited in size to 320 acres to avoid land speculation. In 1859, this limit was raised to 640 acres. This all changed with the 1868 State Tideland Overflow and Reclamation Act. This Act, sometimes referred to as the Green Act because of its champion, Will Green of Colusa, was passed to facilitate the transfer of the public wetlands into private ownership and lead to agricultural exploitation of these lands. Under the new law, developers could purchase as much land as they could reclaim for $1 an acre. Later, after the land was demonstrated to be reclaimed by 3 years of agricultural production, the purchase monies could be refunded to the purchasers for the cost of reclamation and development. This set off a huge surge in reclamation applications; between 1868 and 1871, almost all of these formerly federal public wetlands were transferred into private ownership (Kelley, 1989). Figure 2-2 depicts the Delta during this period.

The 1868 Act provided for the formation of reclamation districts to manage the reclamation process where lands were considered susceptible to reclamation. The following provisions related to the formation of these districts:

- Upon the petition of one-half or more of the land owners within a proposed district area, a reclamation district was to be established by the County Board of Supervisors
- Once the petition had been granted, the petitioners were required to establish such bylaws as they deemed necessary for the work of reclamation, and to maintain the works
- A three-person Board of Trustees was to be elected to manage the reclamation work

The Board of Trustees was empowered to employ engineers and others to survey, plan, and estimate the costs of the work and of the land needed for right of way, including drains, canals, sluices, water gates, embankments, and material for construction, and to construct, maintain, and keep in repair all works necessary for the reclamation of the land.

The County Board of Supervisors was to appoint three commissioners who were to jointly review and assess upon each acre to be reclaimed or benefited a tax proportionate to the whole expense of reclamation. The tax was to be collected and paid into the county treasure and placed to the credit of the reclamation district, to be paid out for the work of reclamation.

In this way, reclamation and flood management was carried out in a more or less piecemeal fashion at the local level for several decades. Figure 2-3 illustrates the reclamation districts created by the end of the 1800s. Much of this system is still in place in the Central Valley and Delta today.

Levee Construction

Most of the early levees in the Delta were constructed by Chinese laborers using hand shovels and wheelbarrows (see Figure 2-4) (Thompson, 1982). Some were constructed using small scraper equipment pulled by horses. Much of the early levee construction efforts in the central Delta employed organic soils excavated by borrow pits near the levee. The organic peats and mucks used in this construction were not ideal levee-construction materials, and an underseepage problem commonly developed at the nearby hole in the ground. Peaty levee material commonly shrank considerably after it dried or blew away. Construction of the levee on the soft soil resulted in irregular settlement and the creation of large cracks and fissures in levee and foundation soils.

As the land subsided and the levees began settling into the soft organic soils, local reclamation districts realized that the levees needed to be continually enlarged simply to keep up with the settling levees and the subsiding island interior. Later, when the farmers realized that levees of sufficient height could not be effectively built or maintained by human or animal labor, steam-powered dredges were used. The hydraulic mining debris that filled Delta channels in the late 1800s only made things worse by choking water conveyance and raising water levels against the levees.

Steam-powered dredges began to be used in the Delta in the 1870s and continued for many decades. Of the different types of dredges, the sidedraft clamshell dredge became particularly popular (Figure 2-5). This dredge typically employed an A-frame and a long boom that could swing to the side. Two cables opened and closed the bucket and swung the boom laterally. This allowed dredging from the watercourse and placement of material on the levee without having to move the hull. Approximately 90 such dredges were estimated to have been built for levee construction in the central part of California (Dutra, 1976).

The general approach would be to dredge alluvial sediments in the sloughs and rivers and deposit the wet, unconsolidated material on the levee. After the dredged muck dried out, it would be shaped into an overall levee cross section. Of course, the heavier mineral sediments commonly resulted in new settlement of the levee, so the process had to be repeated many times.

Dredges were also used to excavate hydraulic mining debris from the channels to facilitate conveyance capacity. They also were used to cut new constructed channels in the Delta (Figure 2-6). The purposes of these new channels were to facilitate navigation and flood flow. Each of these new channels generally needed new levees constructed on both sides of the channels. Unlike natural waterways, there were no natural levees to serve as the base of the levee, so the levees built along constructed channels in the central Delta were often founded on very soft unconsolidated organic soils that experienced major settlement and cracking shortly after construction.

Figure 2-2
Early Map and Offering for Reclaimed Land in the Delta
Source: DWR, 1987

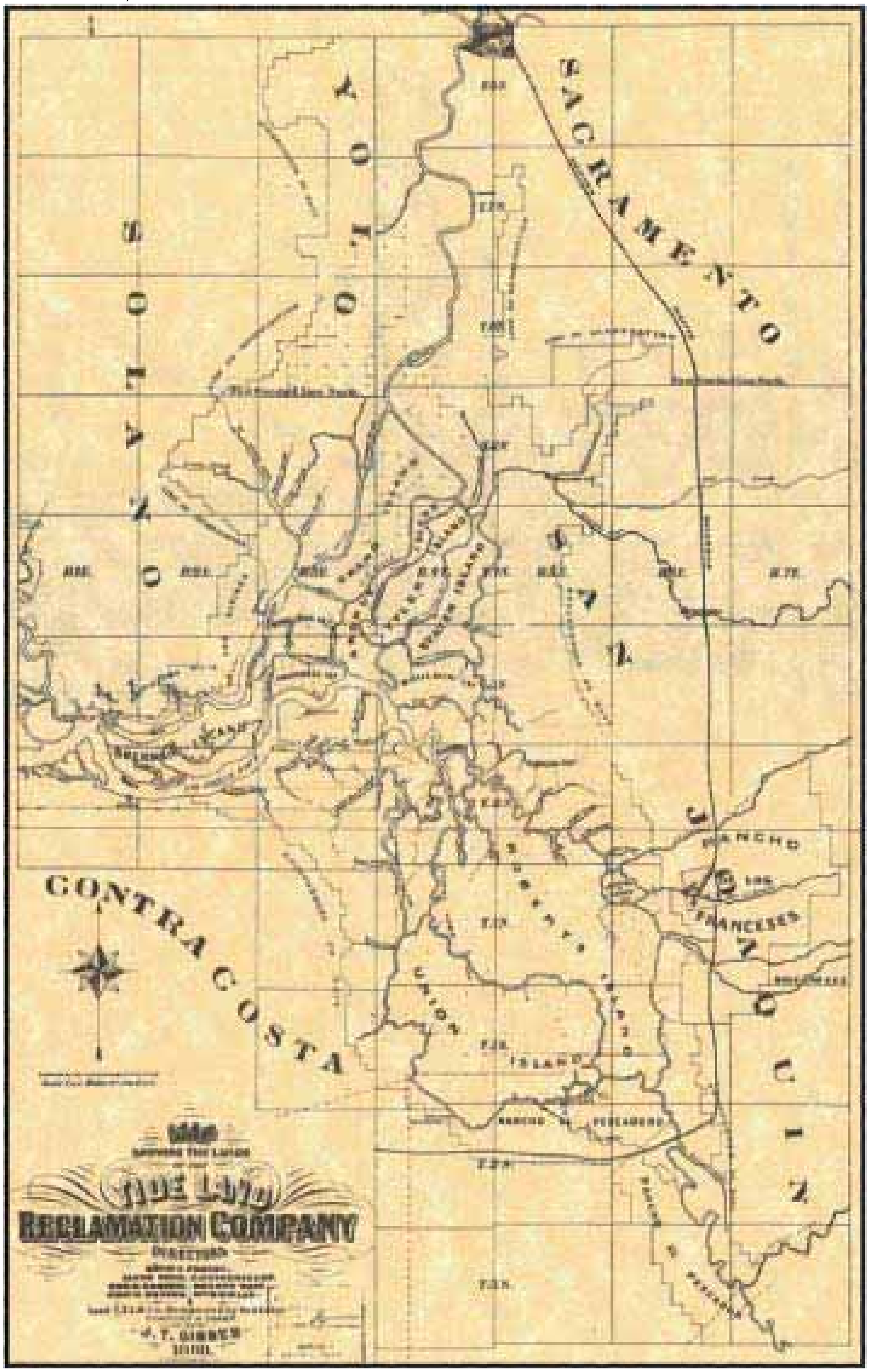


Figure 2-3

Early Reclamation Districts Created in the Sacramento Valley

Source: DWR

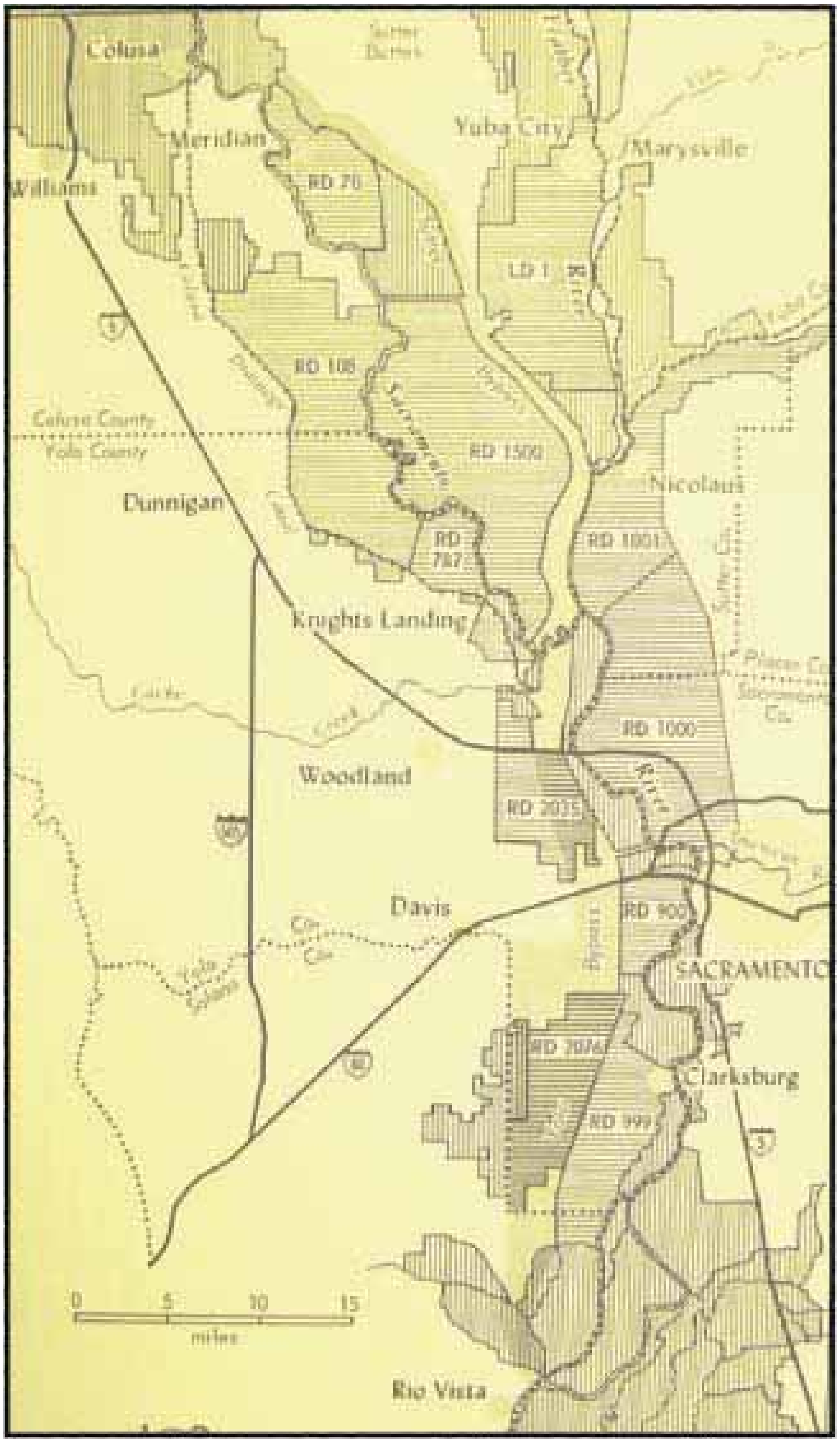


Figure 2-4
Early Levee Construction in the Delta Using Chinese Hand Labor
Source: Thompson, 1982

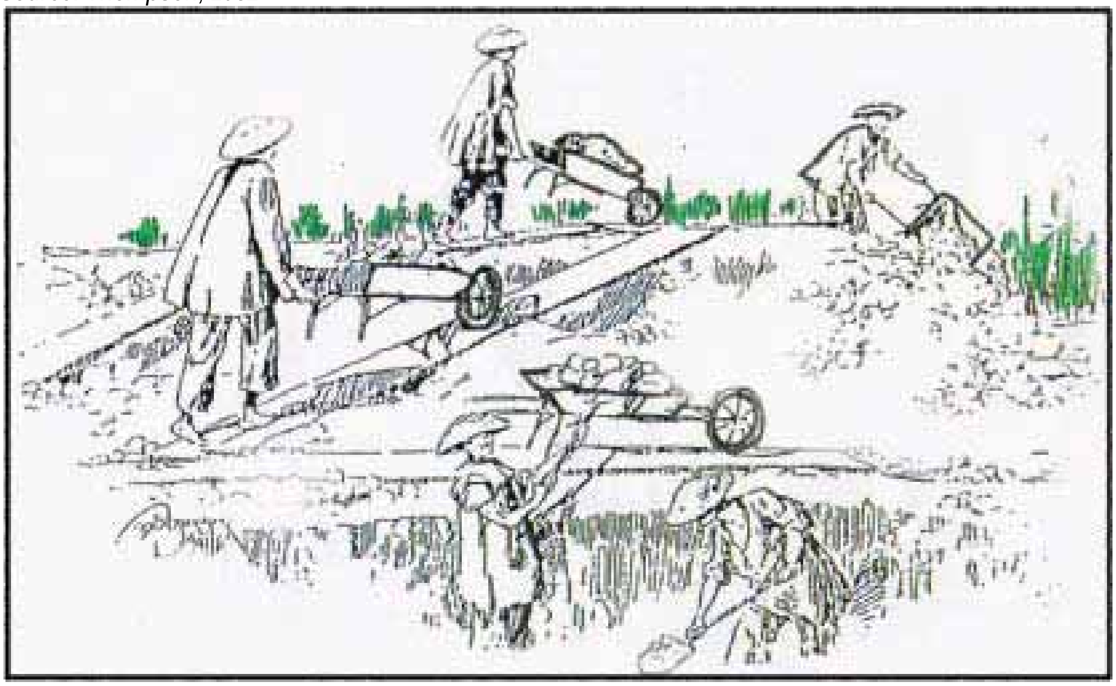


Figure 2-5
Levee Construction Using Sidedraft Clamshell Dredges in the Delta
Source: Dutra, 1976

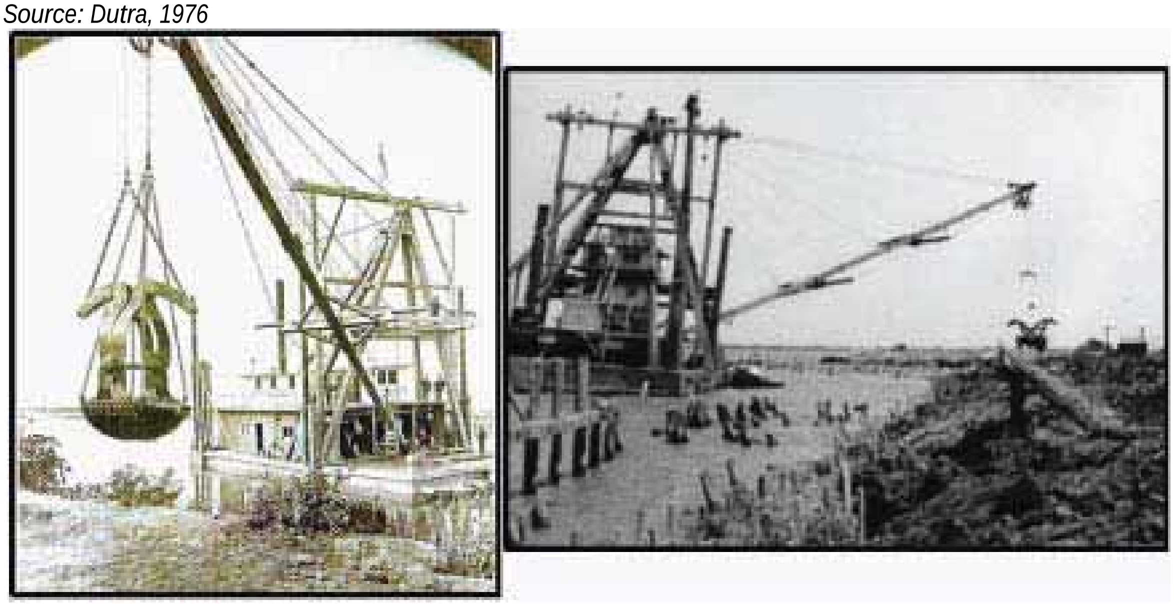
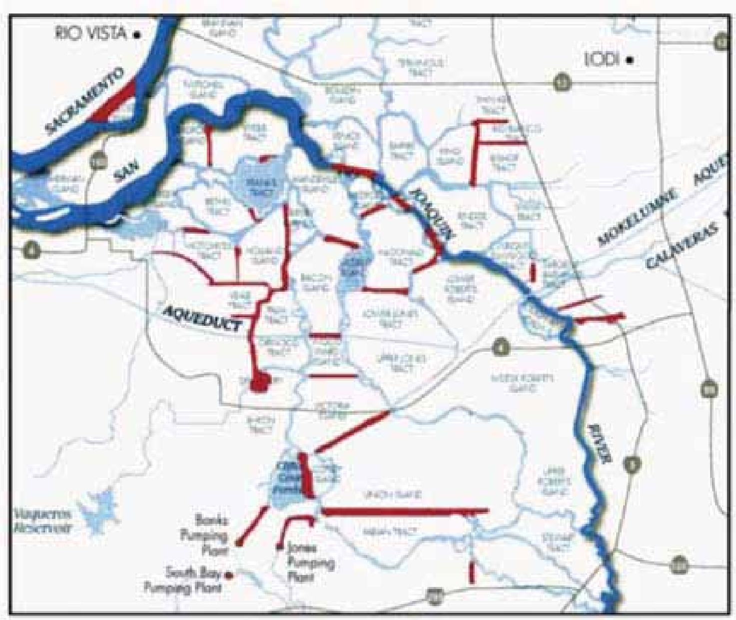


Figure 2-6
Constructed Channels and Canals Cut in the Delta
Source: Delta Vision Strategic Plan, 2008



Subsidence

Much of the central Delta lands are composed of peaty soils that exist naturally as fibrous, low-density, compressible soils usually in a saturated state. To grow crops in such soils, farmers constructed levees and dikes around the tracts and drained the fields. Drying saturated peat reduces its volume by 50 percent. Early cultivation practices included burning, which further reduced the volume and altered the structure. Over time, long-term oxidation chemically reduced the peaty soils to small particles and gases which blew away over time. Today, much of the central Delta is below sea level, with some islands commonly 12 to 15 feet below sea level, requiring levees that are 20 to 25 feet high to hold back water every day. The islands in the central Delta are islands in name only; they are actually subsided bowls with the levees serving as the bowl rims. Figures 2-7 through 2-8 illustrate this condition.

The result of island subsidence over the last 140 years is that relatively small levees have had to evolve into much larger structures to keep the now below-sea-level island interiors from being flooded. ***Unlike most levees such as those in Sacramento or along the Mississippi River, which only hold back water during flood events, Delta levees are among the hardest working levees in the world; the levees in the central Delta hold back water every second of every day of the year.***

Figure 2-7
Evolution of Delta Levees
Source: DWR, 1992

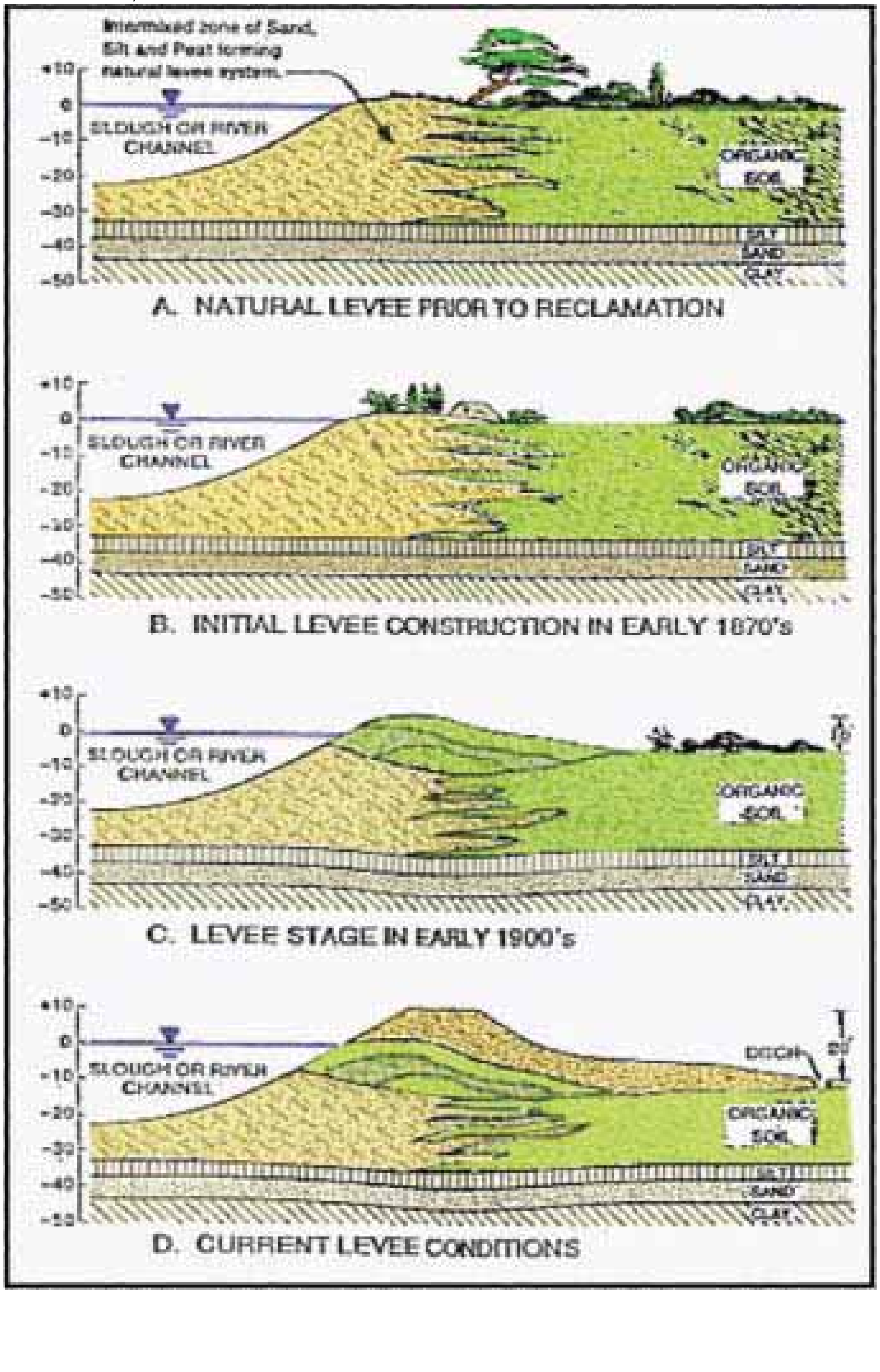


Figure 2-8
Exaggerated Vertical Topography of Bradford Island Illustrating Island Subsidence and "Bowl" Effect
Source: DWR, 2007

Federal Flood-control and Navigation Projects

Structural flood-risk management in California's Central Valley is accomplished using three principal types of facilities:

- Upstream reservoirs to store and attenuate flood flows
- Flood bypasses to convey flood flows out of the river system
- Levees to hold back flood flows within the river system

Approximately 1,600 miles of State-Federal project levees are part of California's federal flood-control projects. This system discharges flood flows into the Delta.

Upstream Water Resources Projects

Dams and reservoirs and other upstream projects affect hydrology and flooding in the Delta. Nineteen major multipurpose dams reduce peak flows in the Delta by impounding runoff from winter storms and spring runoff. Many of these dams have flood-control capacity and release peak flow gradually.

Rivers and stream upstream of the Delta are further controlled by levees to protect urban and agricultural lands. Levees constrain flows that otherwise would be retained in floodplains. Thus, levees tend to increase peak flows into the Delta above pre-reclamation levels.

Sacramento River Flood Control Project

The Sacramento River Flood Control Project consists of the following features:

- Approximately 1,300 miles of levees along the Sacramento River, extending from Collinsville to Chico Landing, at River Mile 194, and the lower reaches of the major tributaries (American, Feather, Yuba, and Bear rivers), minor tributaries, and distributary sloughs in the Delta
- Moulton, Colusa, Tisdale, Fremont, and the Sacramento flood overflow weirs
- Butte Basin, Sutter, and Yolo bypasses and sloughs

The Sacramento River Flood Control Project essentially mimics natural and historic flooding patterns. The project levees begin on the western bank just downstream of Stony Creek. Upstream of the levees, high flows on the river flow into the Butte Basin, a trough created by subsidence, to the east. The Colusa Basin Drain, a similar trough located west of the river, intercepts runoff from westside tributaries.

Project levees were typically built on existing levees. The Central Valley Flood Protection Board operates and maintains the project levees under an agreement with USACE (DWR, 1995). The Sacramento River Flood Control Project levees in the Delta include levees that protect, or partially protect, the following areas (DWR, 1993):

- West Sacramento
- Lands between the Sacramento River and the Sacramento River Deep Water Ship Channel (east levee of the Deep Water Ship Channel)
- Merritt Island
- Sutter Island
- Grand Island
- Ryer Island
- Hastings Tract
- Brannan Island
- Sherman Island

Figure 2-9 illustrates the Sacramento River Flood Control Project.

San Joaquin River Flood Control Project

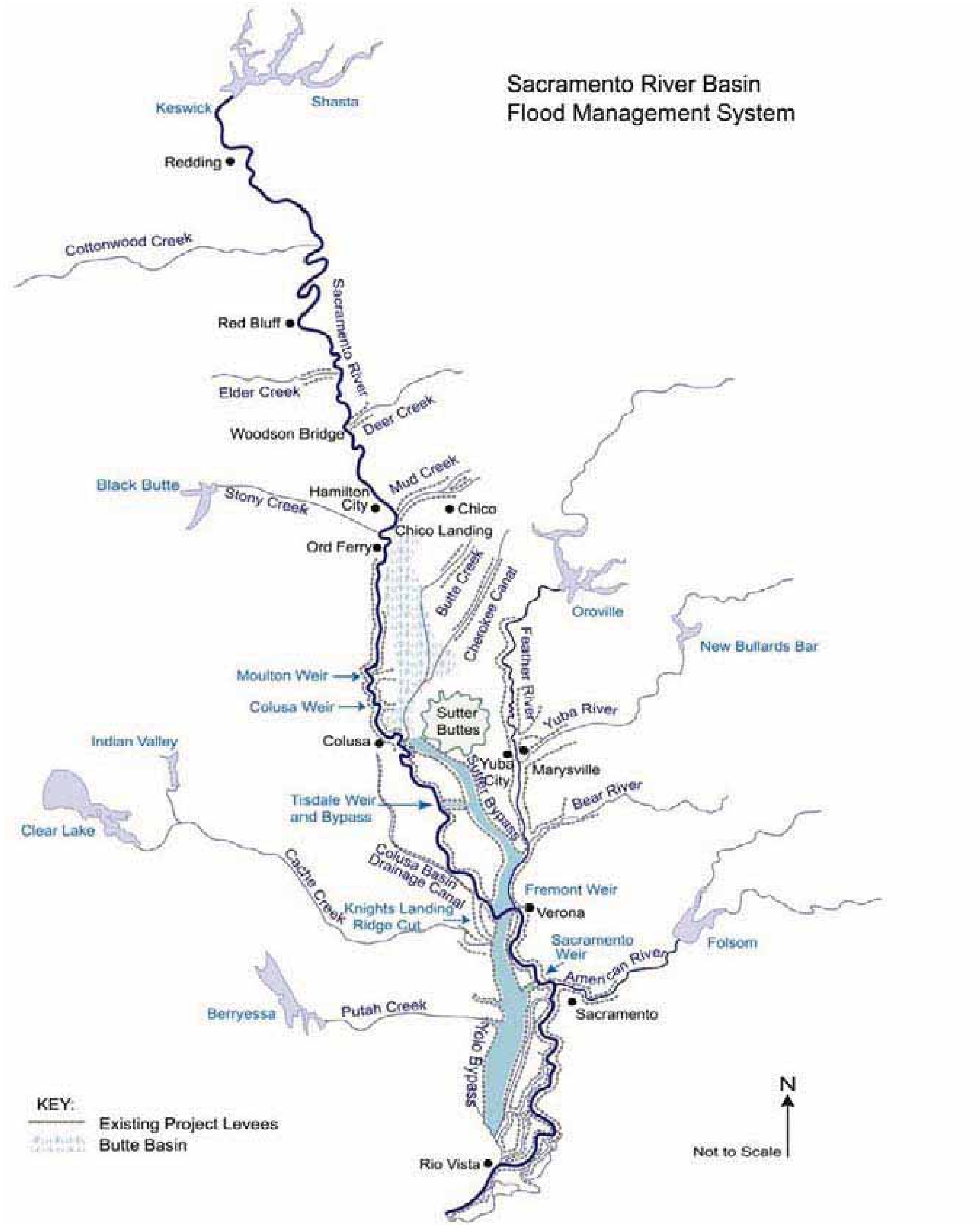
The basic feature of the San Joaquin River flood management system is the San Joaquin River Flood Control Project. This project includes the following features (USACE, 2002a):

- A series of discontinuous levees that extend along the San Joaquin River from the Delta to about opposite the City of Los Banos
- The Chowchilla Canal, Eastside, and Mariposa bypasses

Project levees in the Delta are located along the San Joaquin River, Bear Creek, and the Calaveras River. The system includes the Lower San Joaquin River Flood Control Project, which conveys the San Joaquin River to Stockton. The Lower San Joaquin River Flood Control Project has levees along the San Joaquin River in the Delta and surrounding Stewart Island. Federal project levees are also along Paradise Cut and Old River as far north as Tracy Boulevard, along Middle River as far north as Victoria Canal, and along the lower reaches of the Stanislaus and Tuolumne rivers (USACE, 1999 and 2008).

Figure 2-10 illustrates the San Joaquin River Flood Control Project.

Figure 2-9
The Sacramento River Flood Control Project
Source: USACE, 2002



Delta Levees Summary

Approximately 1,115 miles of levees currently help protect about 700,000 acres of land within the legal limits of the Delta. The levee system helps convey water from the Sacramento, San Joaquin, Cosumnes, Mokelumne, and Calaveras rivers through and around the many islands and tracts in the Delta before discharging to San Francisco Bay or to the forebays of water supply projects. Roughly 40 percent of the drainage water in California travels through the Delta each year (DWR, 1995). Levees in the Delta guide and collect water for agricultural, industrial, and municipal use and are responsible for protecting multiple interests and populations.

Of the 1,115 miles of Delta levees, 385 miles are State-Federal project levees that are part of either the Sacramento River Flood Control Project or the San Joaquin River Flood Control Project, or are part of a federal navigation project (CALFED, 2000a). State-Federal project levees were originally constructed or approved by the federal government and then accepted by the State of California as the non-federal sponsor. The two federal flood-control projects were authorized in 1917 and essentially complete by 1960. In accepting these projects after their completion, the State agreed to indemnify the federal government and to maintain the levees to federal standards. For the most part, the State has turned over the maintenance of these projects to local maintaining agencies such as levee or reclamation districts.

The remaining 730 miles, or about 65 percent, of the levees in the Delta are non-project local levees (CALFED, 2000a). These levees are not part of the federal flood-control program and are maintained by local agencies and reclamation districts. In some cases, the districts are partially reimbursed for levee maintenance and rehabilitation work by state cost-sharing agreements administered by DWR under the Delta Levee Program.

Figures 2-11 and 2-12 illustrate the locations of Project and non-project local levees in the Delta.

Figure 2-10
The San Joaquin River Flood Control Project
Source: USACE, 2002

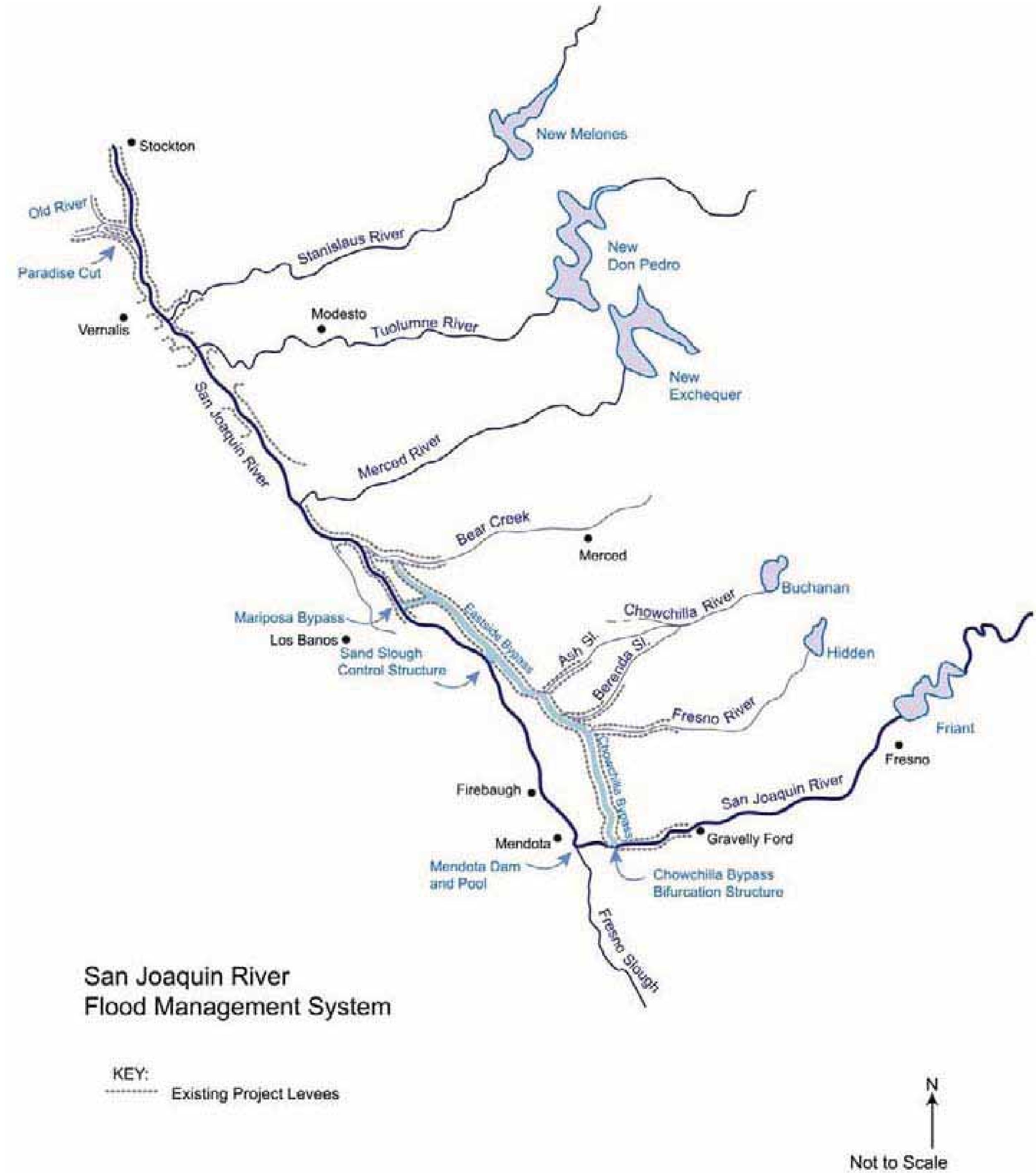


Figure 2-11

State-Federal Project Levees in the Delta

Source: DWR, 2009

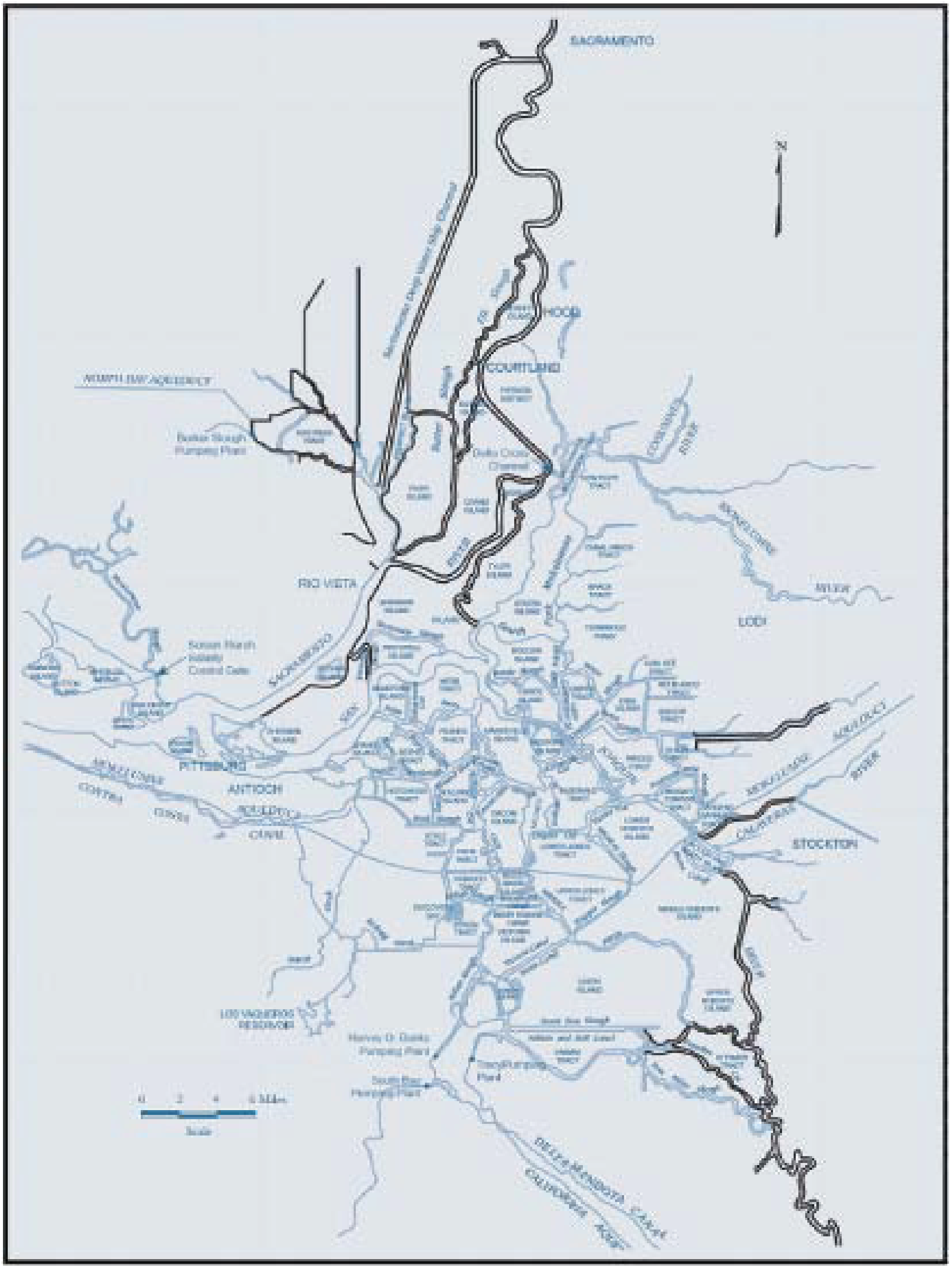
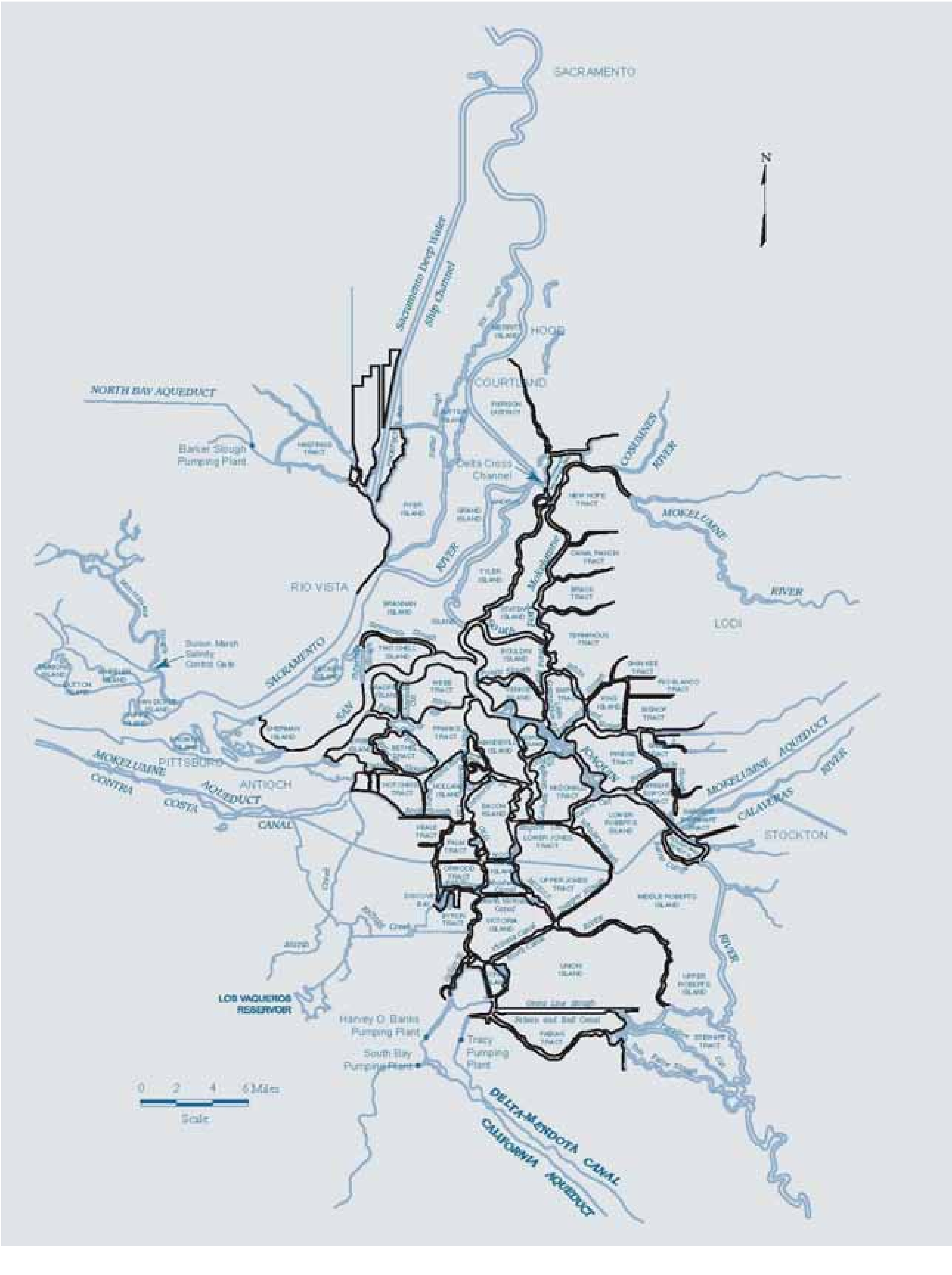


Figure 2-12
Non-Project Local Levees in the Delta
Source: DWR, 2009



Section 3
Current Conditions and Trends

The Delta today bears little resemblance to the natural systems that existed 150 years ago (see Figure 3-1). The legal limit runs from Sacramento at the northern end, down to Stockton and Manteca near the southeast corner, and to Tracy, and Pittsburgh along the southwestern end. Today's Delta includes the following features:

- Over 700,000 acres, mostly agricultural land
- Approximately 65 islands or tracts
- Approximately 1,115 miles of levees (385 miles of State-Federal project levees and 730 miles of non-project local levees)
- Three State highways (Highways 4, 12, and 160)
- A population of approximately 450,000, mostly in communities on the outer fringes of the Delta (the central Delta is relatively sparsely populated)
- Source of major water diversions for the State Water Project (SWP), the Central Valley Project (CVP), and Contra Costa Water District, and for additional water diversions by individual communities and farmers in the Delta itself
- Major route of the East Bay Municipal Utility District's (EBMUD) Mokelumne Aqueduct (three pipelines) providing much of the municipal water supply for the East Bay
- Major route of the Burlington Northern Santa Fe (BNSF) Railway
- Wide variety of other utilities: electrical transmission, communication cables, natural gas pipelines, oil pipelines, and water pipelines
- Land subsidence continuing at a pace reaching approximately 0.5 to 1.5 inches per year in some places
- Declining natural ecosystems and pelagic organisms
- Large variety of introduced and invasive species

Located about 35 miles northeast of San Francisco to the west of the legal Delta, the Suisun Marsh is the largest contiguous brackish water marsh remaining on the West Coast. It is bordered on the south by

Suisun Bay, on the west by Interstate 680, and on the north by State Route 12 and the cities of Suisun and Fairfield (see Figure 3-1). The Suisun Marsh includes the following features:

- 116,000 acres, 52,000 of which are managed wetlands
- 230 miles of levees
- Public waterfowl hunting areas and 158 private duck clubs
- More than 10 percent of California's remaining natural wetlands
- Resting and feeding grounds for thousands of waterfowl migrating on the Pacific Flyway
- Essential habitat for hundreds of species of birds, mammals, fish, and amphibians and reptiles, and important rearing areas for juvenile fish, supporting the commercial salmon fishery
- A variety of recreation opportunities to nearby urban areas

Land Use

The predominant land use within the central Delta is agriculture. This is based on three primary reasons:

1. The Delta Protection Act of 1992 created a Primary Zone within the central Delta (see Figure 3-1), which generally prohibited development
2. Local general plan policies have historically supported agricultural land uses in the primary zone
3. Most levees in the central Delta do not provide a 100-year level of flood protection (a 100-year flood protection means that the probability of flooding in any year is 1 percent).

This latter fact means that under FEMA National Flood Insurance Program (NFIP), development is generally precluded unless the structure can be elevated above the expected flood elevation. Elevating structures as much as 10 to 20 feet, which is what would be required in the central Delta, is generally cost prohibitive.

However, there is significant development in the Secondary Zone around the fringes of the Delta within the communities of Stockton, Tracy, and Oakley. In these communities, local agencies and development interests have been able to fund levee improvements to meet current criteria for 100-year level of flood protection.

Infrastructure

There are two deepwater ports in the Delta: the Port of West Sacramento and the Port of Stockton. Both require ongoing channel dredging and levee maintenance for their continued viability.

State Routes 4, 12, and 160 run through the central Delta. They rely on levee integrity because either they run directly atop the levee systems for portions of their alignment or they are located in lowlands protected by Delta levees (see Figure 3-2). State Route 84, U.S. Highway 99, and Interstate 205 run along the peripheral areas of the Delta. Interstate 5 runs along the eastern portion of the Delta. Numerous county roads run throughout the Delta.

The BNSF Railway is a major rail line into and out of the San Francisco Bay Area. It crosses Lower Roberts Island, Upper and Lower Jones Tract, Bacon Island, and Palm Tract in the central Delta and relies upon the integrity of those islands' levees. Additional rail lines run along the southern portion of the Delta near Tracy.

Figure 3-1
Today's Delta and Suisun Marsh

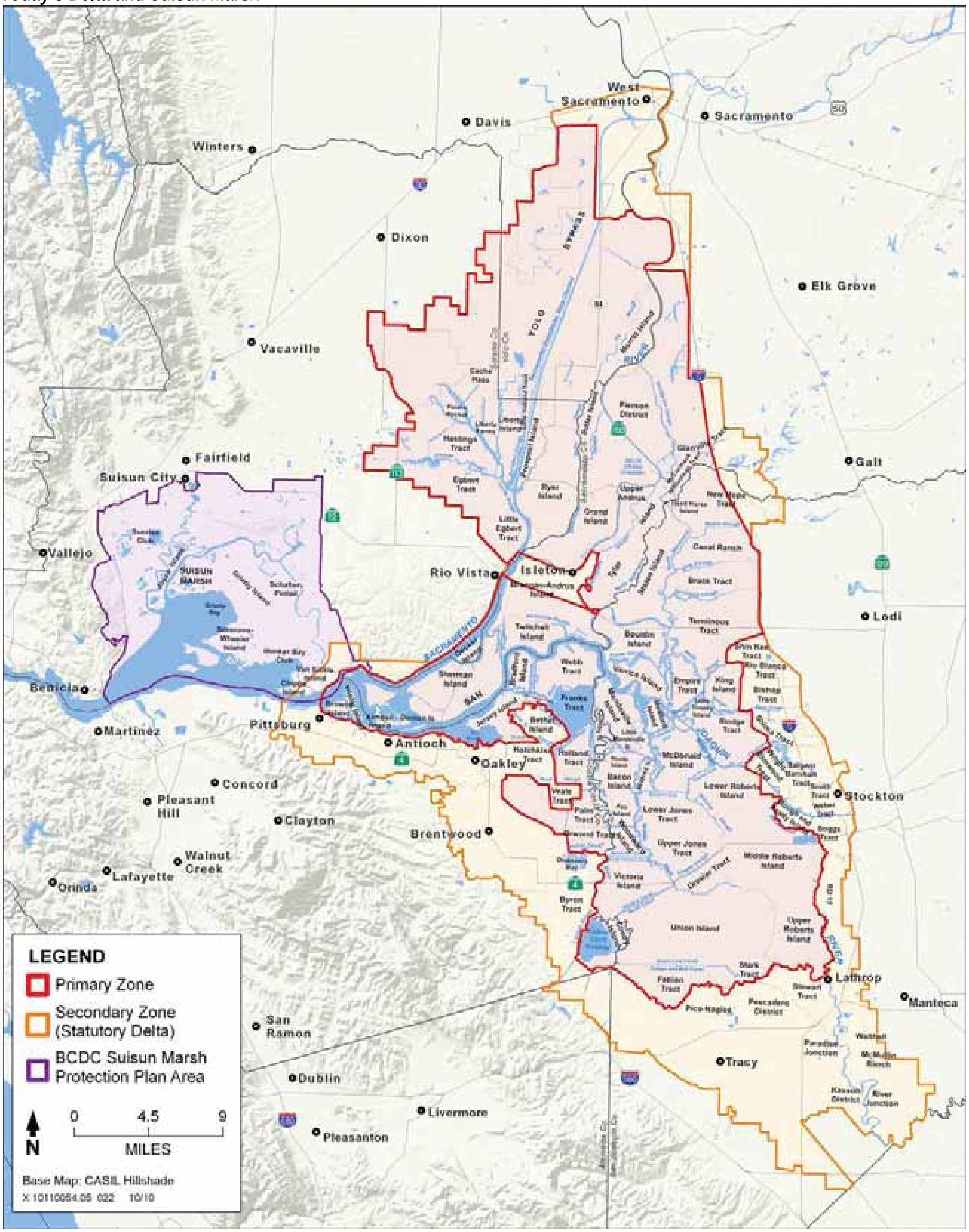
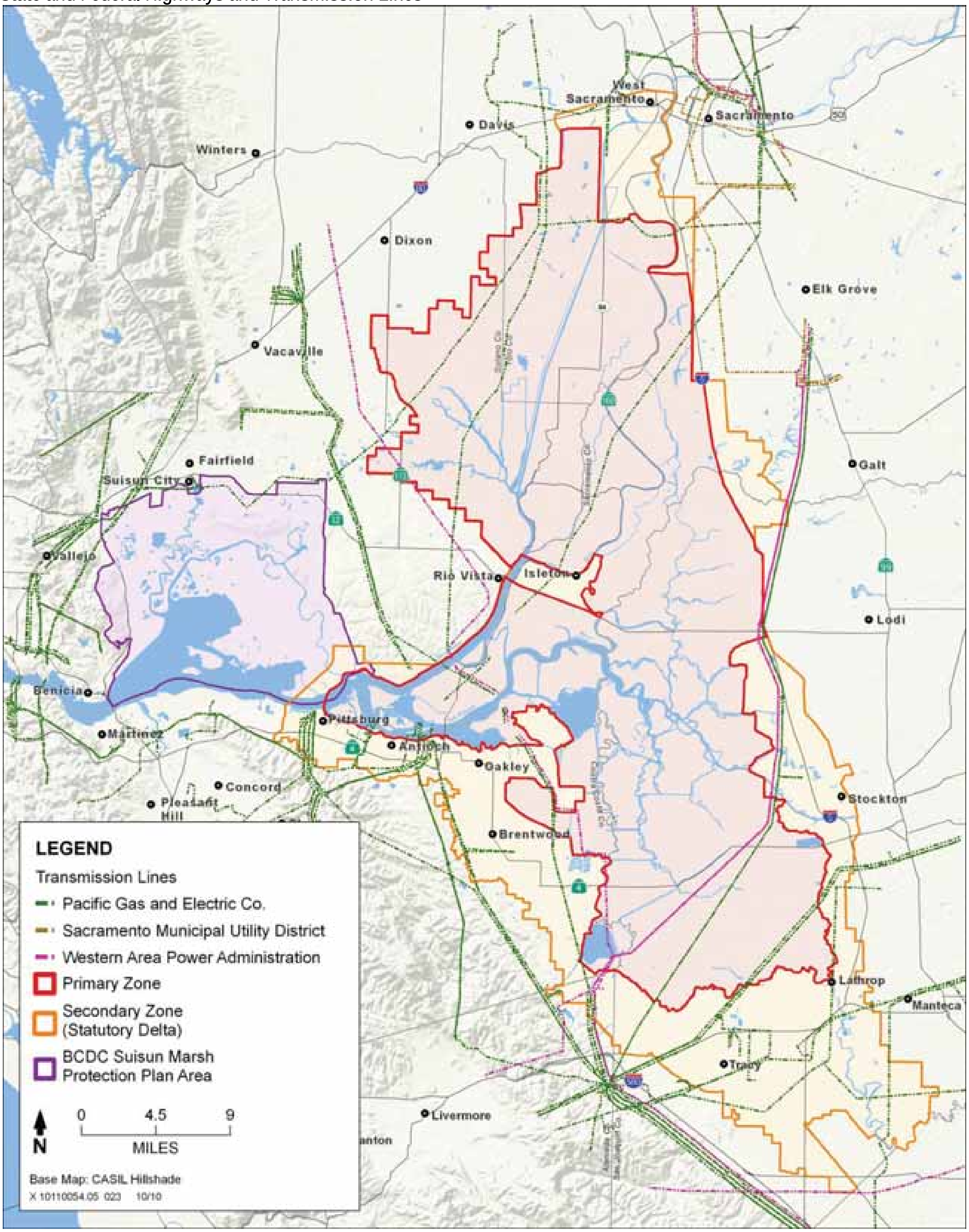


Figure 3-2
State and Federal Highways and Transmission Lines



Numerous power transmission lines of up to 500 kilovolts cross several Delta islands and waterways, including those of the Western Area Power Administration and Pacific Gas and Electric (PG&E).

Natural gas was discovered in the delta in 1935. Today, the Delta serves as both an important natural gas source and an underground gas storage area. PG&E has a major underground natural gas reservoir beneath McDonald Island.

Numerous pressurized oil and natural gas pipelines also run through the Delta. Where these pipelines cross levees, levee instability could result in pipeline ruptures that endanger public safety and the environment.

Numerous irrigation and drainage pumps and pipes serve to import irrigation water and discharge drainage from most Delta islands. Without constant pumping, the below-sea-level islands in the central Delta would fill with water from seepage and underseepage from the adjoining waterways.

Water Diversions

Several major water diversion facilities rely upon Delta levees for either water quality or for the structural support of the facilities themselves:

- The North Bay Aqueduct beginning at Barker Slough in the northern portion of the Delta (DWR). This aqueduct provides water to the City of Vallejo and the Napa Valley.
- The Contra Costa Canal, with intakes on the western portion of the Delta (Rock Slough). This facility provides water to central and eastern Contra Costa County.
- The Mokelumne Aqueduct, which crosses the central Delta in three large pipelines (EBMUD). These pipelines cross several Delta islands and levees and transport water that would have eventually drained into the Delta to the East Bay.
- The South Bay Aqueduct, which, as part of the SWP, is connected to the California Aqueduct (DWR). This canal and pipeline facility provides water to the Livermore and San Jose area and portions of the Silicon Valley.
- The California Aqueduct, which diverts water from Clifton Court Forebay at the southern end of the Delta (DWR). This large water project provides water to the Central Valley, the Central Coast, and Southern California.
- The Delta-Mendota Canal, which diverts water from the Jones Pumping Plant at the southern end of the Delta (federal Bureau of Reclamation). This large federal water project provides water to the Central Valley, mostly for irrigation purposes.

Figures 3-3 through 3-5 illustrate some of these facilities and their locations.

Ecosystems

The scope of the Delta ecosystem and the complexities associated with measuring and understanding its health is sufficiently different from this discussion on flood risk to warrant a separate and focused white paper.

Figure 3-3
SWP and CVP Major Intake Facilities

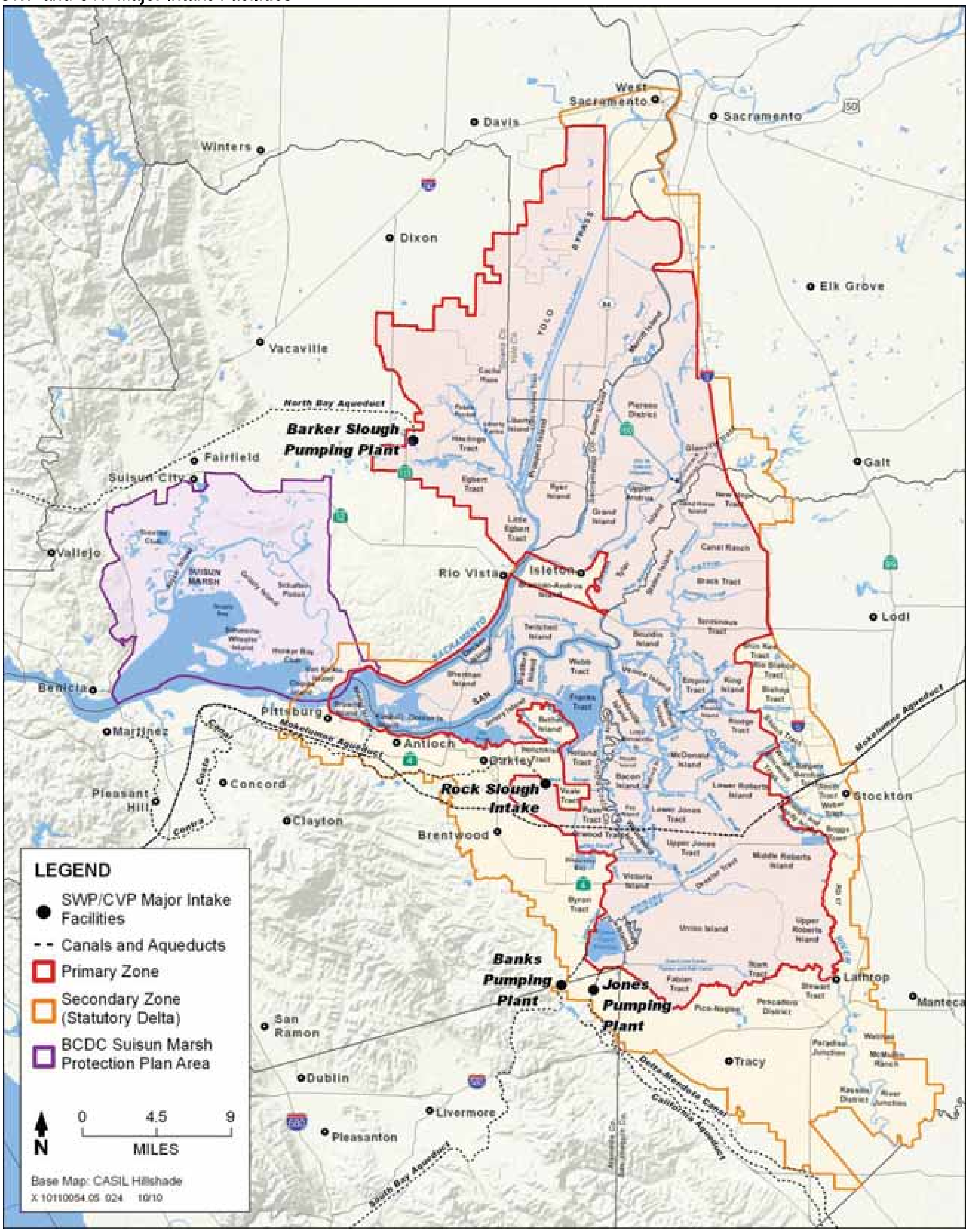


Figure 3-4
DWR's Harvey O. Banks Delta Pumping Plant
Source: DWR, 2009

Figure 3-5
EBMUD's Mokelumne Aqueduct and BNSF Railway on Flooded Jones Tract
Source: DWR, 2004

Levee Vulnerability

The historic levee performance in the Delta has been relatively poor. The original levees were constructed from materials obtained adjacent to the levee footprints and generally loosely placed. In the early days of Delta reclamation, the levees were low in height, and the consequences of failures were readily alleviated. Over time, however, island subsidence caused by the oxidation of organic soils resulted in increased levee heights and larger consequences when levees did fail. Some of the potential modes of levee failure are illustrated in Figure 3-6.

Previous Island Failures

There have been over 100 documented cases where levees failed in the Delta and the protected islands or tracts were inundated by flood waters (see Table 3-1). Since 1960, over 30 levee failures have been documented. These levee failures commonly scour out large portions of the levee and the interior island, sometimes to depths as much as 80 to 90 feet. After the levees were repaired, the local districts often did not backfill the interior scour holes; these can be seen today on various Delta islands (see Figure 3-7).

Note that different sources present different data on past levee failures. For example, in 1997, several failures occurred along the San Joaquin River where it enters the Delta, and these are not included in Table 3-1. Also note that this table includes islands and lowland areas, not upland areas. Although upland areas have also flooded, islands and lowland areas are typically tracked and reported together.

In most cases, the levees failed because of high water created during winter storm events (see Figure 3-8 for examples). High water creates loading conditions that generally contribute to the various modes of potential levee failure shown in Figure 3-6.

However, in some cases, levees have failed in the absence of any type of flood or storm event. The most notable of these was the June 3, 2004, failure of the Upper Jones Tract levee that led to the flooding of approximately half of Upper and Lower Jones Tract, approximately 6,000 acres in total (see Figure 3-9). This levee failure occurred during a sunny late-spring day and reminded many of the vulnerability of the Delta levee system.

The failure rate of Delta levees was generally greater in the early part of the twentieth century than during the latter half because of several factors:

- The construction of upstream storage reservoirs by the mid-1960s helped attenuate flood floods into the Delta.
- The construction of the two federal flood-control projects significantly improved about one-third of the levees in the Delta.
- Some of the islands that flooded in the early part of the century were not reclaimed. Consequently, they could not fail again, and this diminished the potential number of levee failures from those points forward.
- The State of California began funding the Delta Levee Subventions and Special Projects programs in the 1980s as a result of ongoing levee failures. These grant monies helped fund levee maintenance and improvements in many areas of the Delta since that time.
- A larger amount of attention and resources has been given to flood fighting and responding to levee problems in the Delta.

Figure 3-6
Potential Modes of Failure for Delta Levees

Figure 3-7
Scour Ponds from Past Levee Failures in the Delta

Table 3-1

History of Delta and Suisun Island and Lowland Flooding
Source: URS/JBA, 2008

Year	Number of Islands Flooded	Islands Flooded
1900	2	Jersey Island and New Hope Tract
1901	4	Clifton Court Tract, Fabian Track, RD 17, and Victoria Island
1902	1	Brannan-Andrus Island
1904	11	Bishop Tract, Brack Tract, Sargent-Barnhart Tract, Staten Island, Ryer Island, Tyler Island, Bouldin Island, Jersey Island, Sherman Island, Brannan-Andrus Island, and Venice Island
1905	1	New Hope Tract
1906	7	Lower Roberts Island, Union Island, Fabian Tract, Twitchell Island, Lower Jones Tract, Sherman Island, and Venice Island
1907	19	Byron Tract, Coney Island, Palm Tract, Lower Jones Tract, Terminous Tract, Clifton Court Tract, Sargent-Barnhart Tract, Staten Island, Victoria Island, Franks Tract, Ryer Island, Twitchell Island, Tyler Island, Bethel Island, Brannan-Andrus Island, Bouldin Island, Jersey Island, New Hope Tract, Venice Island
1908	2	Bethel Island and Bouldin Island
1909	4	Brannan-Andrus Island, Bethel Island, Sherman Island, and Venice Island
1911	2	Bethel Island and RD 17
1920	2	Middle Roberts Island and Paradise Junction
1925	1	RD 1007
1927	1	Big Break
1928	1	New Hope Tract
1932	1	Venice Island
1936	3	Medford Island, Franks Tract, and Quimby Island
1937	2	Donlon Island and Sherman Island
1938	11	Bacon Island, Mandeville Island, Middle Roberts Island, Rhode Island, Pescadero Tract, Stewart Tract, Franks Tract, Shin Kee Tract, Quimby Island, McCormack-Williamson Tract, and Venice Island
1950	15	Bradford Island, Empire Tract, Ida Island, Webb Tract, Pescadero Tract, Stewart Tract, McMullin Ranch, RD 17, Paradise Junction, Quimby Island, Dead Horse Island, McCormack-Williamson Tract, New Hope Tract, Upper Roberts Island, and Venice Island
1955	8	Grand Island, Empire Tract, Ida Island, Jersey Island, Quimby Island, Dead Horse Island, McCormack-Williamson Tract, and New Hope Tract
1958	5	Terminous Tract, Shin Kee Tract, Dead Horse Island, McCormack-Williamson Tract, and River Junction
1963	2	Little Holland Tract and Prospect Island
1964	1	McCormack-Williamson Tract
1965	2	Mildred Island and Shin Kee Tract
1969	2	Mildred Island and Sherman Island
1971	1	Rhode Island
1972	1	Brannan-Andrus Island
1980	6	Holland Tract, Little Mandeville Island, Lower Jones Tract, Webb Tract, Dead Horse Island, and Prospect Island
1981	2	Little Franks Tract and Prospect Island

Table 3-1
History of Delta and Suisun Island and Lowland Flooding
Source: URS/JBA, 2008

Year	Number of Islands Flooded	Islands Flooded
1982	3	Little Franks Tract, McDonald Island, and Venice Island
1983	10	Edgerly Island, Shima Tract, Fay Island, Grizzly Island, Bradford Island, Van Sickle Island, Little Franks Tract, Mildred Island, Prospect Island, and River Junction
1986	8	Glanville Tract, Shin Kee Tract, Dead Horse Island, Little Mandeville Island, Prospect Island, McCormack-Williamson Tract, New Hope Tract, Tyler Island,
1994	1	Little Mandeville Island
1995	1	Prospect Island
1997	11	Dead Horse Island, McCormack-Williamson Tract, Prospect Island, McMullin Ranch, Paradise Junction, River Junction, Walthall Tract, Wetherbee Lake, Glanville Tract, Pescadero Tract, Stewart Tract
1998	2	Grizzly Island and Van Sickle Island
2004	1	Upper Jones Tract
2005	1	Simmons-Wheeler Island
2006	4	Honker Bay Club, Fay Island, Simmons-Wheeler Island, and Van Sickle Island

Figure 3-8
Levee Failures during Flood Events
Source: DWR, 2007

Figure 3-9
Breach in Upper Jones Tract Levee on June 3, 2004
Source: DWR

Although Delta levees are still at an unacceptable level of performance, the above measures have helped moderate the failure rates of Delta levees.

In most previous levee failures, the breaches in the levees were closed by either the USACE or by the local levee districts. However, after the floods of 1986, the USACE stated that they would no longer reclaim flooded islands that were protected by non-Project levees. When the 2004 Jones Tract levee failure occurred, the USACE again reiterated its policy of not reclaiming flooded islands flooded by non-Project levees. As a result, Governor Schwarzenegger directed DWR, for the first time ever, to close the breach and pump out the floodwaters inundating the two tracts.

Flooded Islands Not Reclaimed

In the past, not all Delta islands were reclaimed after flooding. Several large and small islands were never reclaimed after their levees failed:

- Western Sherman Island, approximately 5,000 acres, abandoned in 1878
- Franks Tract, approximately 3,300 acres, abandoned in 1938
- Big Break, approximately 2,200 acres, abandoned in 1927
- Mildred Island, approximately 1,000 acres, abandoned in 1986
- Little Franks Tract
- Little Mandeville Island

In addition, Clifton Court Tract was converted into Clifton Court Forebay as part of the State Water Project and was permanently inundated in the 1960s.

Levee Standards: Current Levels of Protection

Levee standards are based on providing a prescribed level of safety and reliability. They must be designed for reliable performance to meet various loading factors:

- Flood and tidal stages which will increase due to climate changes
- Current and wave action
- Continuing island subsidence
- Earthquakes
- Environmental factors including vegetation growth (trees) and animal burrows

During the last few decades, state and federal agencies have developed various levee standards. These standards were designed to either establish minimum criteria that would make the levees and the properties protected eligible for grants or rehabilitation funds, or minimum criteria that would allow development behind the levees. The four most prominent existing standards are listed below:

- **FEMA Hazard Mitigation Plan:** Meeting this standard allows the Delta island or tract to be eligible for FEMA disaster grants and assistance following levee failures and island inundation.

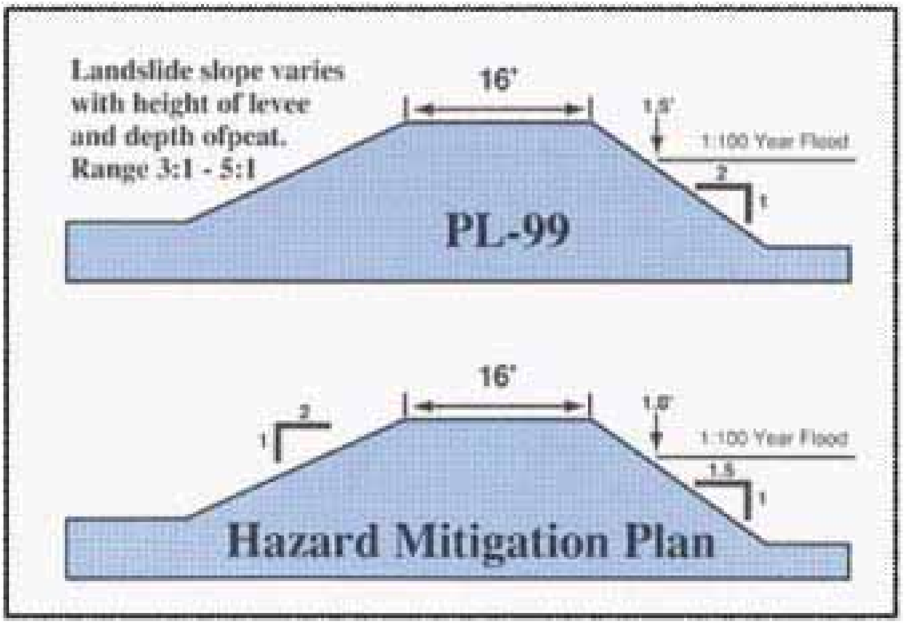
- **USACE Public Law 84-99:** Meeting this standard allows the Delta island or tract to be eligible for USACE funding for levee rehabilitation and island restoration following levee failures and island inundation, provided the reclamation district applies for and is accepted into the program and passes a rigorous initial inspection and periodic follow-up inspections.

Both of the above two standards are based primarily on levee geometry with minimum freeboard and maximum steepness of slopes (see Figure 3-10). Although there is a minimum slope stability factor of safety implied by the geometry, neither standard is associated with a level of protection and neither addresses seismic stability.

- **FEMA 100-year (Base Flood) Protection:** This standard, often called the 1 percent annual chance flood level of protection, is based on criteria established in the Code of Federal Regulations and is often used with established USACE criteria to meet certain freeboard, slope stability, seepage/underseepage, erosion, and settlement requirements. Meeting this level of flood protection means that communities will not require mandatory purchase of flood insurance or be subject to building restrictions. This standard generally does not address seismic stability. Very few levees in the central Delta meet this standard.

- **DWR 200-year Urban Levee Protection:** This standard is similar to the FEMA standard, but for a 200-year level of flood protection. It is generally based on established USACE criteria. However, unlike USACE criteria, the DWR 200-year Urban Levee Protection requires that seismic stability be addressed. Not meeting this standard, or making adequate progress towards it, will generally prohibit further development behind an urban or urbanizing levee. Although almost none of the levees in the central Delta meets this standard, most do not protect urban areas, with the exceptions of the outer fringes of the Delta near West Sacramento, Sacramento's Pocket Area, and Stockton.

Figure 3-10
Delta Levee Criteria and Standards Based on Levee Geometry
Source: DWR, 2007



Current Delta Levee Funding Programs

State Delta Levees Maintenance Subvention Program

The Delta Levees Maintenance Subvention Program is a cost-sharing program in which participating local levee maintenance agencies receive funds for the maintenance and rehabilitation of non-project levees in the Delta. The program's goal is "to reduce the risk to land use associated with economic activities, water supply, infrastructure, and ecosystem from catastrophic breaching of Delta levees by building all Delta levees to the Bulletin 192-82 Standard" (DWR, 1995). There is a statewide interest in levee maintenance in the Delta because the leveed islands maintain flow velocities in the sloughs and channels that combat saltwater intrusion. The program is authorized in the California Water Code, Sections 12980–12995. In 1988, with the passage of the Delta Flood Protection Act, financial assistance for several communities maintaining local Delta levees was increased through the Delta Levees Subvention Program. The intent of the program is given in Water Code Article 12981:

> *"(a) The Legislature finds and declares that the Delta is endowed with many invaluable and unique resources and that these resources are of major statewide significance.*

> *"(b) The Legislature further finds and declares that the Delta's uniqueness is particularly characterized by its hundreds of miles of meandering waterways and the many islands adjacent thereto; that, in order to preserve the Delta's invaluable resources, which include highly productive the Delta's invaluable resources, which includes highly productive agriculture, recreational assets, fisheries, and wildlife environment, they physical characteristics of the Delta should be preserved essentially in their present form; and that the key to preserving the Delta physical characteristics is the system of levees defining the waterways and producing the adjacent islands. However, the Legislature recognizes that it may not be economically justifiable to maintain all Delta islands.*

> *"(c) The Legislature further finds and declares that funds necessary to maintain and improve the Delta's levees to protect the physical characteristics should be used to fund levee work that would promote agriculture and habitat uses in the Delta consistent with the purpose of preserving the Delta's invaluable resources."*

The Central Valley Flood Protection Board is responsible to sponsor and approve levee repair and enters into agreements with Reclamation Districts to reimburse eligible levee rehabilitation or maintenance costs. The state will provide funding for up to $20,000 per levee mile for all Delta levee maintenance. Islands in the central Delta that border the San Joaquin and Sacramento rivers play an important role in maintaining Delta hydraulics, and thus tend to have higher per-mile expenditures than other parts of the Delta.

State Special Projects Program

The Delta Levees Special Flood Control Projects (Special Projects) provides financial assistance to local levee-maintaining agencies for levee rehabilitation in the Delta. The program was established by the California Legislature under Senate Bill 34 in 1988. Since the inception of the program, more than $200 million has been provided to local agencies in the Delta for flood control and related habitat projects. The Special Projects program is authorized in the California Water Code, Sections 12310 through 12318. The intent of the legislation, as stated in the Water Code, is to preserve the Delta as much as it exists at the present time (DWR, 2009a). Beyond Delta levees, Section 12311 of the Water Code states that the program includes "approximately 12 miles of levees bordering Northern Suisun Bay from Van Sickle Island westerly to Montezuma Slough."

The program has traditionally focused on flood-control projects and related habitat projects for eight western Delta islands (Bethel, Bradford, Holland, Hotchkiss, Jersey, Sherman, Twitchell, and Webb) and for the towns of Thornton and Walnut Grove. Because of recent increases in funding, the program is now being extended to the rest of the Delta, as was authorized by the Legislature in 1996.

DWR FloodSAFE California Program

In January 2005, Governor Schwarzenegger called for improved maintenance, system rehabilitation, effective emergency response, and sustainable funding to lower flood risks in California. In 2006, DWR launched FloodSAFE California, a multifaceted program to improve public safety through integrated flood management. Water Code Section 9602 (added by Senate Bill 5) also requires a minimum level of flood protection for urban areas in the Sacramento and San Joaquin river watersheds so they can withstand flooding that has a 1-in-200 annual chance of occurrence. FloodSAFE California goals include:

- Reduce the frequency and size of flooding of communities
- Reduce the consequences of flooding
- Protect and enhance ecosystems (DWR, 2008a)

State Propositions 1E and 84, with legislative direction, authorized as much as $3.3 billion of state bond funds to the Central Valley and Delta for repairs and improvements to levees and flood projects, although the vast majority of these funds are expected to be used to improve flood protection of urban areas in the Central Valley. The majority of the bond funds that will be directed toward Delta levees are expected to go through the Delta Levees Subventions and Special Projects funds.

DWR is also in the early stages of preparing the Central Valley Flood Protection Plan, a strategic plan intended to identify a long-term strategy for flood risk reduction in the Central Valley. This includes updating data on hydrology and existing projects, formulating and evaluating alternatives, and delivering a recommended plan. The scope of the Central Valley Flood Protection Plan includes the facilities of the two State-Federal flood-control projects, plus any additional existing flood-management facility that provides significant systemwide flood risk management benefits. This plan is scheduled to be completed by January 1, 2012 (DWR, 2008c).

Another FloodSAFE effort that will affect Delta flood management is the Central Valley Floodplain Evaluation and Delineation Program. This program's objectives are to provide floodplain information for risk identification and public notification, support the Central Valley Flood Protection Plan, provide reliable floodplain information for local decision making, and provide design support for early implementation of flood protection projects. Central Valley Floodplain Evaluation and Delineation Program maps have been developed that represent 100- and 200-year floodplains for urban and urbanizing areas within the Sacramento–San Joaquin Valley watershed. These maps will be further developed based on more detailed hydrologic and hydraulic information, topographic data, and levee evaluations.

Other DWR flood-management activities include statewide flood forecasting, flood operations, and other key flood emergency-response activities. DWR Levee Flood Protection Zone maps have been developed that represent floodplain areas protected by Central Valley State and federal project levees. DWR has also developed advisory floodplain maps known as Best Available Maps. These represent floodplain maps based on both FEMA data and the best available local data, and summarize 100- and 200-year floodplain maps for 32 counties and 91 cities in the Sacramento–San Joaquin Valley watershed. The purpose of the maps is to identify potential flood hazards that warrant further study and consideration during land use planning. DWR also produces Awareness Floodplain Maps. These maps display the 100-year flood hazard areas using approximate assessment procedures. These floodplains will be shown simply as flood-prone areas without specific depths.

USACE Delta Levee Funding

The CALFED Act (Public Law 108-361) directed the USACE to identify and prioritize levee stability projects that could be carried with federal funds. An initial amount of $90 million was authorized, with another $106 million authorized in the 2007 Water Resources Development Act. The USACE initially solicited proposals for various levee improvement projects and received 68 project proposals totaling over $1 billion. In the short-term, the USACE plans to proceed with implementation of high-priority improvements that can be constructed with the limited funds appropriated to date. The following funding has been received in the last three fiscal years:

- Fiscal year 2008: $4.9 million
- Fiscal year 2009: $4.8 million
- Fiscal year 2010: $4.8 million

The USACE also is proceeding with a Delta Islands and Levees Feasibility Study to develop long-term plans for flood-risk management, water quality, water supply, and ecosystem restoration. In addition, the USACE is working on a Lower San Joaquin Feasibility Study to determine if there is a federal interest in providing flood risk management and ecosystem restoration on the lower San Joaquin River.

Private Development

Private development at the fringes of the Delta in the Secondary Zone has funded several levee-improvement programs in order to meet the FEMA 100-year level of flood protection. This has included areas in Stockton on the east and Oakley on the west. Probably the most prominent plan is associated with the proposed conversion of Stewart Tract within the City of Lathrop from traditional agriculture to an upscale residential community. The project, known as River Islands, is planned to incorporate very large levees with 300-foot widths and 10:1 interior slopes for urban flood protection and to provide home lots with views of the river systems. The overall project is expected to require over 10 years and expenditures exceeding $1 billion.

Funding Challenges

The current levee funding programs require a local cost share. Depending upon the project and the program, the local cost share ranges from 25 to 50 percent of the total project cost. In most cases, the local Delta reclamation districts could meet this requirement either with cash or in-kind services. However, with much more State money available in the short term, local agencies will find it difficult to meet traditional cost-sharing requirements. Consideration should be given to at least temporarily reducing the cost-sharing requirements. The Delta Levees Special Project Program has authority to increase the State cost share. The Legislature could provide similar discretion for the Subventions Program.

Flood Damage Liability and the Paterno Decision

The USACE and other federal agencies are afforded immunity from liability of any kind for damages arising from flood events through the provisions of the Flood Control Act of 1928. The primary purpose of the immunity provision was to avoid having to pay flood damages in addition to the very substantial costs of flood-control projects that were being contemplated by the federal government. However, this immunity is not enjoyed by parties outside of the federal government. The most notable recent court decision on flood liability was the November 2003 *Paterno vs. State of California* decision. The California Court of Appeals found the State liable, by inverse condemnation, for damages incurred by flooded residents as a result of a levee failure on the Yuba River, near Marysville, during the 1986 flood. The State was held responsible for defects in a Yuba County levee foundation that existed when the levee was constructed by local agricultural interests in the 1930s and later incorporated into the Sacramento River Flood Control Project. In this case, the State of California was the non-federal sponsor for the federal flood-control project and accepted the project from the USACE when it was completed. The State also gave assurances to the federal government that the levee would be maintained to federal standards even though the State later turned over the maintenance of the levee to a local maintaining agency, Reclamation District 784. The Court found that when a public entity operates a flood-control system built by someone else, it accepts liability as if it had planned and built the system. So, the State of California was held liable and settled with the plaintiffs for an award of approximately $500 million for a levee that the State did not design, build, or even directly maintain. The court also found that the State of California had an inadequate State Plan of Flood Control. The *Paterno* decision makes it possible that the State will ultimately be held responsible for the structural integrity of much of the federal flood-control system in the Central Valley – approximately 1,600 miles of State-Federal project levees that protect more than half a million people and property exceeding $50 billion in value. This large potential liability was a major factor that led to the development of the FloodSAFE California program and the bond funds available for the Central Valley.

The Paterno decision liability is generally not considered applicable to non-Project levees in the Delta because the State never accepted these projects from the federal government; they were never part of a federal flood-control project. However, the State was sued by a railroad for the 2004 levee failure at Jones Tract. The basis for the suit was that the State provided financial assistance to the local levee reclamation district (Delta Levee Subventions Program) and that it later inspected the funded work, verifying that the funds were spent for their authorized purposes. The nature of that inspection is hotly debated and, to date, the suit has not been adjudicated.

In another California court case, *Arreola vs. Monterey County*, local agencies were held liable in July 2002 for 1995 flood damages to property owners that resulted from a failure to properly maintain the Pajaro River project. The maintaining agencies had not been able to use standard mechanical clearing methods to remove vegetation in the channel because of environmental requirements to protect riparian habitat. Alternative methods to clear the channel had proved inadequate and costly. This decision exposes all levee maintaining organizations, including the State, to major future liabilities.

Section 4
Jurisdictional Responsibilities

A multitude of federal, State, and local agencies have jurisdiction within the Delta regarding land use, flood protection, levee maintenance, water quality, and environmental issues. This has, in part, led to some of the frustration regarding the implementation of change or reform within the legal boundaries of the Delta. Depending on the specific location and history, federal, State and local agencies may all have some level of jurisdiction or responsibility for a given reach of levee. Although not intended to be comprehensive, the following discussion attempts to describe the jurisdiction and responsibility of several of the more prominent agencies involved in Delta flood protection.

Federal Agencies

FEMA

This agency is responsible for establishing and maintaining minimum federal standards for floodplain management within the United States and territories of the United States. As discussed below, FEMA plays a major role in managing and regulating floodplains. FEMA is responsible for management of floodplain areas, which are defined as the lowland and relatively flat areas adjoining inland and coastal waters subject to a 1 percent or greater chance of flooding in any given year (the 100-year floodplain). FEMA also helps develop the Flood Insurance Rate Maps (FIRMs), which delineate the Special Flood Hazard Areas (SFHAs) and the risk premium zones applicable to the community for flood insurance purposes.

Flood Zone Regulations

SFHAs are subject to federal and State requirements, which are defined primarily by federal regulations at 44 CFR 60.3 and 44 CFR 65.12. The first citation, 44 CFR 60.3(b)(6,7,10), requires the following:

> *Notify, in riverine situations, adjacent communities and the State Coordinating Office prior to any alteration or relocation of a watercourse, and submit copies of such notifications to the Administrator;*

> *Assure that the flood carrying capacity within the altered or relocated portion of any watercourse is maintained;*

> *Require until a regulatory floodway is designated, that no new construction, substantial improvements, or other development (including fill) shall be permitted within Zones A1–30 and AE on the community's Flood Insurance Rate Map (FIRM), unless it is demonstrated that the cumulative effect of the proposed development, when combined with all other existing and anticipated development, will not increase the water surface elevation of the base flood more than one foot at any point within the community.*

These federal regulations are intended to address the need for effective floodplain management and provide assurance that the cumulative effects of floodplain encroachment do not cause more than a 1-foot rise in water surface elevation after the floodplain has been identified on the FIRM (local flood ordinances can set a more stringent standard). The absence of a detailed study or floodway delineation places the burden on the project proponent to perform an appropriate engineering analysis to prepare hydrologic and hydraulic analyses consistent with FEMA standards. These analyses would then be used to evaluate the proposed project together "with all other existing and anticipated development." Defining future anticipated development is difficult. The purpose of this requirement is to avoid inequitable encroachments into the floodplain.

For projects that are discovered to cause any increase in water surface elevations, 44 CFR 65.12, "Revision of flood insurance rate maps to reflect base flood elevations caused by proposed encroachments," states:

> *(a) When a community proposes to permit encroachments upon the floodplain when a regulatory floodway has not been adopted or to permit encroachments upon an adopted regulatory floodway which will cause base flood elevation increases in excess of those permitted under paragraphs (c)(10) or (d)(3) of § 60.3 of this subchapter, the community shall apply to the Administrator for conditional approval of such action prior to permitting the encroachments to occur and shall submit the following as part of its application:*
>
> *(1) A request for conditional approval of map change and the appropriate initial fee as specified by § 72.3 of this subchapter or a request for exemption from fees as specified by § 72.5 of this subchapter, whichever is appropriate;*
>
> *(2) An evaluation of alternatives which would not result in a base flood elevation increase above that permitted under paragraphs (c)(10) or (d)(3) of § 60.3 of this subchapter demonstrating why these alternatives are not feasible;*
>
> *(3) Documentation of individual legal notice to all impacted property owners within and outside of the community, explaining the impact of the proposed action on their property;*
>
> *(4) Concurrence of the Chief Executive Officer of any other communities impacted by the proposed actions;*
>
> *(5) Certification that no structures are located in areas which would be impacted by the increased base flood elevation;*
>
> *(6) A request for revision of base flood elevation determination according to the provisions of § 65.6 of this part;*
>
> *(7) A request for floodway revision in accordance with the provisions of § 65.7 of this part.*

The provisions of this regulation require either demonstration that the proposed project would cause no effect on the base flood elevations, or else the project must obtain a Conditional Letter of Map Revision before permitting the project for construction. Also, as suggested, if the project causes no effect on the base flood elevations, it can be approved by the floodplain administrator for the community without any approvals by FEMA or Conditional Letter of Map Revision submittals to FEMA. However, the floodplain administrator can require a Conditional Letter of Map Revision if it is felt that the project is of sufficient complexity to warrant FEMA's review.

The minimum federal regulatory requirement pertaining to encroachments into the floodway is defined by 44 CFR 60.3(d)(3):

> *Prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels within the community during the occurrence of the base flood discharge.*

This regulation applies only to encroachments into the floodway. When there is such an encroachment, the FEMA effective hydraulic model should be used to evaluate the impacts and mitigation options for the encroachment.

FEMA Levee Design and Maintenance Regulations

For levees to be accredited by FEMA, and to allow communities to participate in Preferred Risk programs of the NFIP, evidence must be provided that adequate design, operation, and maintenance systems are in place to provide reasonable assurance that protection from the base flood (1 percent annual chance of exceedance or 100-year flood) exists. These requirements are outlined in 44 CFR, Volume 1, Chapter I, Section 65.10 and are summarized below.

- **Freeboard.** Riverine levees must provide a minimum freeboard of 3 feet above the water surface level of the base flood. An additional 1 foot above the minimum is required within 100 feet on either side of structures (such as bridges) riverward of the levee or whatever the flow is constructed. An additional 0.5 foot above the minimum at the upstream end of the levee, tapering to not less than the minimum at the downstream end of the levee, is also required.
- **Closure.** All openings must be provided with closure devices that are structural parts of the system during operation and designed according to sound engineering practice.
- **Embankment protection.** Engineering analyses must be submitted demonstrating that no appreciable erosion of the levee embankment can be expected during the base flood as a result of either currents or waves, and that anticipated erosions will not result in failure of the levee embankment or foundation directly or indirectly through reduction of the seepage path and subsequent instability.
- **Embankment and foundation stability.** Engineering analyses that evaluate levee embankment stability must be submitted. The analyses provided shall evaluate expected seepage during loading conditions associated with the base flood and shall demonstrate that seepage into or through the levee foundation and embankment will not jeopardize embankment or foundation stability.
- **Settlement.** Engineering analyses must be submitted that assess the potential and magnitude of future losses of freeboard as a result of levee settlement and demonstrate that freeboard will be maintained within the minimum standards.
- **Interior drainage**. Analysis must be submitted that identifies the source(s) of such flooding, the extent of the flooded area, and, if the average depth is greater than 1 foot, the water surface elevation(s) of the base flood.
- **Operation Plans.** For a levee system to be recognized, a formal plan of operation must be provided to FEMA. All closure devices or mechanical systems for internal drainage, whether

manual or automatic, must be operated in accordance with an officially adopted operational manual, a copy of which must be provided to FEMA.

- **Maintenance Plans.** For levee systems to be recognized as providing protection from the base flood, they must be maintained in accordance with an officially adopted maintenance plan. All maintenance activities must be under the jurisdiction of a federal or State agency, an agency created by the federal or State law, or an agency of a community participating in the NFIP that must assume ultimate responsibility for maintenance. The plan must document the formal procedure that ensures that the stability, height, and overall integrity of the levee and its associated structures and system are maintained. At a minimum, maintenance plans shall specify the maintenance activities to be performed, the frequency of their performance, and the person, by name or by title, responsible for their performance.

The information submitted to support that the levee complies with the above requirements must be certified by a registered professional engineer. Certified as-built plans of the levee must also be submitted.

Procedure Memorandum 34

Procedural Memorandums (PMs) supplement and clarify the information in Appendix H of FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners (2003) regarding mapping the base flood in areas with levees. PM 34, Interim Guidance for Studies Including Levees, provides FEMA staff, contractors, and mapping partners with guidance for the evaluation and mapping of levees and levee-affected areas as part of the FEMA Flood Map Modernization Program (FEMA, 2010). The most important aspect of this PM is that communities must provide documentation that the levees do indeed provide the base level of flood protection, or the levees will not be considered to exist in the modernization of the maps.

Procedure Memorandum 43

PM 43, Guidelines for Identifying Provisionally Accredited Levees (PALs), provides FEMA staff, contractors, and mapping partners with guidance for identifying Provisionally Accredited Levees and mapping levee-affected areas. Also included is a fact sheet, prepared in question-and-answer format, that provides detailed information regarding NFIP procedures for evaluating and mapping levee systems with emphasis on PM 43 and Provisionally Accredited Levee systems. This fact sheet was designed for a more technical audience. Additional documents include flow charts and sample letters for different levee scenarios (National Committee on Levee Safety, 2009). The PAL process was created to give communities that believe that their levees provide a 100-year-level of flood protection a 2-year period to develop and provide the documentation that this protection truly exists. At the end of the PAL 2-year period, if the communities have not provided this documentation, FEMA will remap the community and flood basin assuming that the levees do not exist.

Hazardous Mitigation Plan Criteria

Guidance regarding HMPs for state and local agencies is provided in 44 CFR 201. HMPs are necessary for receiving grant funding under the Stafford Act for prevention planning. The states must demonstrate a commitment to risk reduction from natural hazards, including levee failure. HMPs act as guidance for state decision-makers in determining the appropriation of resources to the reduction of these risks.

National Flood Insurance Program

FEMA administers the NFIP. The NFIP has two main components:

- Floodplain management assistance
- Flood insurance assistance

The purpose of flood insurance is to enable property owners to purchase insurance against losses from physical damage or the loss of buildings and their contents caused by floods, flood-related mudslides, or erosion. Insurance is available to property owners belonging to NFIP-participating communities. The NFIP is administered by the Federal Insurance Administration under FEMA. Participation in the NFIP also makes communities eligible for federal flood disaster assistance. For a community to be eligible to participate in the NFIP, the community must adopt a local floodplain management ordinance that meets or exceeds the minimum federal standards defined in 44 CFR 60–65. Participating communities must adhere to all floodplain management requirements, with oversight from FEMA, for all activities that may affect floodplains within the Special Flood Hazard Areas.

As part of the NFIP, FEMA provides one or more FIRMs (discussed previously in the Floodplain Delineation section). Each FIRM contains flood zones used to determine a community’s flood insurance rates and floodplain development restrictions. It identifies which communities are federally required to carry flood insurance. (For example, communities can choose to participate or not participate in the NFIP. Homeowners in SFHAs with federally backed mortgages may be required to carry flood insurance, but otherwise may not be required to carry insurance.) Flood zones are areas delineated to represent areas with similar flood risk, flood-protection infrastructure, flood-protection infrastructure certifications, and designated floodways. FEMA requires that local governments covered by federal flood insurance pass and enforce a floodplain management ordinance that specifies minimum requirements for any construction within the 100-year floodplain.

Guidance and criteria for levees included in the NFIP are provided in 44 CFR 65.10. The major criteria within the document include freeboard, closure structures, embankment protection, embankment and foundation stability, settlement, interior drainage, and other design criteria. Operation and maintenance requirements are also discussed. Each of these criteria includes specific design guidelines that must be met in order for the levee to remain in the NFIP. It should be noted that FEMA is not responsible for evaluating these levees; the evaluation is performed by others, which leads to FEMA accreditation when FEMA adopts the certification completed by a professional engineer.

USACE

The following discussion provides an overview of the USACE regulatory responsibilities that apply to navigable waters and construction within the ordinary high water mark of other waters of the United States. In addition, the USACE constructs flood risk reduction and ecosystem restoration projects and monitors their operations and maintenance. It also provides emergency response to floods. These functions are also described.

1936 Flood Control Act

The USACE constructs local flood-control and risk-management projects and navigation projects in the Delta. Supplementing the 1917 and 1928 Flood Control Acts, the Flood Control Act of 1936 established a nationwide policy that flood control on navigable waters or their tributaries is in the interest of the general public welfare and is, therefore, a proper activity of the federal government in cooperation with states and local entities. The 1936 Act, its amendments, and subsequent legislation specify details of federal participation. Projects are either specifically authorized through legislation by Congress or through a small projects blanket authority. Typically, a feasibility study is done to determine federal interest before authorization or construction. The USACE currently has a Delta feasibility study underway. A study under the American River Common Features authority is also currently studying additional flood protection for the City of Sacramento that could involve alteration to Sacramento River levees or the Yolo Bypass in the Delta. The planned San Joaquin River Basin Study will evaluate more flood protection for the City of Stockton and vicinity. The West Sacramento Feasibility Study is evaluating flood protection for the City of West Sacramento.

USACE Rehabilitation and Inspection Program

The Rehabilitation and Inspection Program (RIP) is the USACE's program that provides for the inspection of flood-control projects, the rehabilitation of damaged flood-control projects, and the rehabilitation of federally authorized and constructed hurricane or shore-protection projects. Levees in the program are eligible for federally funded repair and rehabilitation for damage induced by flood events, provided funding is available. The Project levees in the Delta, those levees previously authorized or constructed under a federal flood-control project, are eligible for the program as long as the non-federal sponsor maintains the levees to certain federal standards. Repairs and rehabilitation are accomplished under provisions of Public Law 84-99, with some cost-sharing normally required for non-Project levees.

In order for non-project levees in the Delta to be eligible, the local maintaining agency must first apply for participation into the program. In order to be admitted, the levees must meet certain standards, mostly geometry, and be maintained to federal levee standards, and pass a rigorous initial inspection. Once admitted to the program, they must also pass subsequent routine inspections to remain in the program. Very few levees in the central Delta meet these standards or pass the initial inspections. Remaining in the program will be more challenging in the future, even for Project levees, because the USACE has begun enforcing more stringent vegetation standards that call for no woody vegetation at all on the levees, or within 15 feet of the levees.

USACE Navigation Projects

Federal interest in navigation is established by the Commerce Clause of the Constitution and court decisions defining the right to improve and protect navigable waterways in the public's interest. The USACE navigation projects in the Delta include Suisun Bay Channel, Sacramento River Deep Water Ship Channel, and Stockton Deep Water Ship Channel. Associated with navigation is the Long Term Management Strategy for Delta Sediments. This is a plan to coordinate and manage dredging for navigation, flood risk management, water conveyance, and recreation; stabilize levees; and protect ecosystems. Technical work groups are engaged in pilot studies, preparing orders and permits for dredging and beneficial reuse, and compliance with environmental laws. The Suisun Channel in the Suisun Marsh is a USACE navigation project to maintain a navigable connection between the City of Suisun and Grizzly Bay (USACE, 2006; USACE, 2010).

Clean Water Act

The Clean Water Act established the basic structure for regulating discharges of pollutants into waters of the United States and gave the U.S. Environmental Protection Agency (USEPA) the authority to implement pollution control programs such as setting wastewater standards for industry. The Clean Water Act sets water quality standards for all contaminants in surface waters and allows the USEPA to delegate some of its authority for enforcing such standards to states (the California State Water Resources Control Board is the agency that helps enforce water quality standards in California). The law employs a variety of regulatory and non-regulatory tools to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff.

Section 404 of the Clean Water Act establishes programs to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Activities in waters of the United States that are regulated under this program include fills for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and conversion of wetlands to uplands for farming and forestry. Under Section 404, any person or public agency proposing to locate a structure, excavate, or discharge dredged or fill material into waters of the United States or to transport dredged material for the purpose of dumping it into ocean waters must obtain a permit from the USACE. The USACE has jurisdiction over all waters of the United States including, but not limited to, perennial and intermittent streams, lakes, ponds, as well as wetlands in marshes, wet meadows, and side hill seeps. Clean Water Act Section 404(b)(1) guidelines provide environmental criteria and other guidance used in evaluating proposed discharges of dredged materials into waters of the United States.

Operations and Maintenance Controls, Flood-control Projects

The maintenance and operation of federal project levee structures is discussed in 33 CFR 208.10. According to these regulations, no improvement shall be passed over, under, or through the walls, levees, improved channels, or floodways, nor shall any excavation or construction be permitted within the limits of the project right-of-way, nor shall any change be made in any feature of the works without prior determination by the District Engineer of the Department of the Army or his or her authorized representative that such improvement, excavation, construction, or alteration will not adversely affect the function of the protective facilities. This regulation is the basis for requiring a permit prior to any construction at federal project levees. Types of alterations or modifications typically covered by a 208 permit include bridges, pump houses, stairs, pipes, bike trails, and power poles.

Rivers and Harbors Act of 1899

Title 33 United States Code 408 and Section 14 of the Rivers and Harbors Act of 1899 (RHA) provide that the Secretary of the Army, on the recommendation of the Chief of Engineers, may grant permission for the temporary occupation or use of any sea wall, bulkhead, jetty, dike, levee, wharf, pier, or other work built by the United States. This permission will be granted by an appropriate real estate instrument in accordance with existing real estate regulations. This regulation is used to require permits prior to modifications of federal project levees. Types of alterations typically requiring a Section 408 permit are major modifications such as degradations, raisings, and realignments.

Sections 9 and 10 of RHA authorize the USACE to regulate the construction of any structure or work within navigable waters. The RHA authorizes the USACE to regulate the construction of infrastructure such as wharves, breakwaters, or jetties; bank protection or stabilization projects; permanent mooring structures, vessels, or marinas; intake or outfall pipes; canals; boat ramps; aids to navigation; or other modifications affecting the course, location condition, or capacity of navigable waters. The USACE jurisdiction under RHA is limited to “navigable water,” or waters subject to the ebb and flow of the tide shoreward to the mean high water mark that may be used to transport interstate or foreign commerce. The USACE must consider the following criteria when evaluating projects within navigable waters: (1) the public and private need for the activity; (2) reasonable alternative locations and methods; and (3) beneficial and detrimental effects on the public and private uses to which the area is suited (City of Stockton, 2005).

Emergency Flood Control Funds Act of 1955

In addition to regulatory activities, the USACE has a number of projects and functions that can potentially affect activities in the Delta. The Emergency Flood Control Fund Act, Public Law 84-99, authorizes emergency funding and response for levee repairs and flood preparation. The USACE can provide flood-fighting readiness within hours; however, this action is supplemental to services provided by local reclamation districts and State agencies. The USACE and DWR have a working relationship through a memorandum of understanding originally drafted in 1955 and amended since then (USACE, 2005).

Executive Order 11988, Floodplain Management

Under Executive Order 11988, all federal agencies are charged with floodplain management responsibilities when planning or designing federally funded projects or when considering any permit applications for which a federal agency has review and approval authority. These responsibilities include taking action to reduce the risks of flood losses, including adverse impacts to human safety, health, and welfare. Federal agencies also are charged with the responsibility of restoring the natural and beneficial values of floodplains. If a proposed action is located within a floodplain, measures should be identified to minimize flood hazards, and floodplain mitigation requirements should be incorporated into the proposed action.

Water Resources Development Act of 2007

The Water Resources Development Act of 2007 (Public Law 110-114) includes the National Levee Safety Act of 2007 (Title IX), which established the National Levee Safety Committee. The Committee was charged with developing recommendations for a National Levee Safety Program. The recommendations were transmitted to Congress in a January 15, 2009, draft report. The Committee is continuing to develop a strategic implementation plan and to work with Congressional staff on potential legislation to implement the recommendations.

This act also charged the USACE to complete an inventory and inspection of all federal levees in the United States.

Bureau of Reclamation

The United States Bureau of Reclamation (Reclamation) owns and manages several dams and distribution canals upstream of and within the Delta as part of the federal CVP. Its upstream reservoirs and dams include such major facilities as Shasta, Folsom, New Melones, and Friant dams. These multipurpose facilities regulate flows to the Delta and provide water supply, hydroelectric, flood-control, recreation, and other benefits. Reclamation consults with the State and provides technical assistance related to reservoir reoperation studies.

Reclamation also owns and operates the C.W. Bill Jones Pumping Plant, previously known as the Tracy Pumping Plant, as part of the CVP. This large pumping plant diverts water from the southern portion of the Delta into the Delta-Mendota Canal. Consequently, Reclamation's water exports are also highly dependent upon the water quality in the Delta, just as is the SWP. However, unlike the State of California, which provides funds for the maintenance and improvements of Delta levees, Reclamation provides no funding for levees in the Delta.

State Agencies

Department of Water Resources

DWR is an organization within the State of California's Resources Agency. DWR's mission is to manage the State's water resources, in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. Within this mission, DWR has the specific responsibility of "protecting public health, life, and property by regulating the safety of dams, providing flood protection, and responding to emergencies." DWR meets these responsibilities through the following activities:

- Continually supervising design, construction, enlargement, alteration, removal, operation, and maintenance of more than 1,200 jurisdictional dams
- Encouraging preventive floodplain management practices; regulating activities along Central Valley floodways
- Maintaining and operating specified Central Valley flood-control facilities

- Cooperating in flood-control planning and facility development
- Maintaining the State-Federal Flood Operations Center and the Eureka Flood Center to provide flood advisory information to other agencies and the public
- Cooperating and coordinating in flood emergency activities and other emergencies

DWR also owns and operates the SWP, with numerous water storage and conveyance facilities throughout the state. DWR exports water from the Delta at its North Bay Pumping Plant at Barker Slough and at the Harvey O. Banks Pumping Plant in the south Delta.

DWR was created following the severe flooding across Northern California in December 1955. Although flood forecasting and flood operations were integral functions of DWR and its preceding agencies for nearly a century, DWR further established the Division of Flood Management in November 1977.

The Division of Flood Management, together with other divisions in DWR, is carrying out the work of the DWR's FloodSAFE California Program, which partners with local, regional, state, tribal, and federal officials in creating sustainable, integrated flood-management and emergency-response systems throughout California. The Division of Flood Management comprises six primary offices. These include the Hydrology and Flood Operations Office, FloodSAFE Program Administration Office, the Central Valley Flood Planning Office, the Flood Projects Office, the Levee Repairs and Floodplain Management Office, and the Flood Maintenance Office. The Delta Suisun Marsh Office was previously a component of the Division of Flood Management; however, it is now the Environmental Stewardship and Statewide Resources Office under the FloodSAFE Program (FESSRO).

The Hydrology and Flood Operations Office is responsible for directing the DWR's flood and water supply forecasting operations, hydrology and climatology studies, emergency flood operations, and flood-control project inspections and encroachment permitting. This office also includes the California State Climatologist. The Flood Projects Office is responsible for the planning, design, and construction of structural and nonstructural flood-control projects, including those sponsored by the Central Valley Flood Protection Board, local agencies, and the USACE, as well as implementing statewide flood-control grants programs. The Levee Repairs and Floodplain Management Office is responsible for administering programs aimed at reducing the threat of loss of life and damage to property through evaluation and direct rehabilitation of structural deficiencies in California's levee system, and through the encouragement and use of nonstructural alternatives and practices. The office, through its components, Levee Repairs, Levee Evaluations and Floodplain Management, in coordination with FloodSAFE Program Administration Office and the Central Valley Flood Planning Office, will develop the Central Valley Flood Protection Plan. The Flood Maintenance Office is responsible for the operation and maintenance of the federally constructed flood-control features in the Sacramento Valley as authorized by the Water Code Sections 8361 and 12878 and cooperates with the USACE in repairing flood-damaged federal flood-control projects maintained under the authority of the Central Valley Flood Protection Board. Maintenance includes planning, environmental permitting and coordination, and design through the Maintenance Support Branch, and field operations through the Sutter Maintenance Yard and the Sacramento Maintenance Yard.

Central Valley Flood Protection Board

Following the federal 1850 Swamp and Overflow and the state 1868 Tideland Overflow and Reclamation Acts, reclamation districts were formed and reclaimed wetlands and constructed levees on a more-or-less piecemeal basis. The Central Valley Flood Protection Board, previously known as the Reclamation Board, was created in 1911. Its purpose was to help manage flood risks in the Central Valley on a systemwide basis through the development of a comprehensive flood-control plan for the Sacramento and San Joaquin rivers, and to act as the non-federal sponsor for federal flood-control projects in the Central

Valley. The Central Valley Flood Protection Board has jurisdiction throughout the Sacramento and San Joaquin valleys, which is synonymous with the drainage basins of the Central Valley, and includes the Sacramento–San Joaquin Drainage District.

The Central Valley Flood Protection Board mission is as follows:

- To control flooding along the Sacramento and San Joaquin rivers and their tributaries in cooperation with the USACE
- To cooperate with various agencies of the federal, State, and local governments in establishing, planning, constructing, operating, and maintaining flood-control works
- To maintain the integrity of the existing flood-control system and designated floodways through the Board's regulatory authority by issuing permits for encroachments

The Central Valley Flood Protection Board is a major partner of Federal Flood Control works. The Board shares costs with the federal government and the local districts and provides land easements and right of way for federal projects. The Board assumes responsibility for operation and maintenance only after a local maintenance agency has agreed to assume ultimate responsibility for the operation and maintenance. The Board also approves or denies plans for reclamation, dredging, or improvements that alter any project levee. It has authority to approve or deny any land reclamation plan (related to public works) or flood protection that involves excavation near rivers and tributaries, and has legal responsibility for oversight of the entire Central Valley flood-management system.

The Central Valley Flood Protection Board also adopts floodway boundaries and approves uses within those floodways. The purpose of the designated floodway program is to control encroachments and development within the floodways and to preserve floodways to protect lives and property. Various uses are permitted in the floodways, such as agriculture, canals, low dikes and berms, parks and parkways, golf courses, sand and gravel mining, structures that will not be used for human habitation, and other facilities and activities that will not be substantially damaged by the base flood event and will not cause adverse hydraulic impacts that will raise the water surface in the floodway. A permit from Central Valley Flood Protection Board is required for most activities other than normal agricultural practices within the boundaries of designated floodways. The only designated floodways in the Delta are along the Cosumnes and Mokelumne rivers up to their confluence with each other and the Stanislaus River up to its confluence with the San Joaquin River.

State Regulations on Levee Standards

Title 23 of the California Code of Regulations provides guidance to the Central Valley Flood Protection Board on how to enforce appropriate standards for flood-control projects in the Central Valley.

California Water Code Section 5000, et seq., provides a means for counties to finance the reclamation of land that has been made unusable by overflow or flooding.

Assembly Bill 1200

Assembly Bill 1200 (Laird, Chapter 573, Statutes of 2005) highlighted the complex Delta water issues and directed DWR and the California Department of Fish and Game to report to the Legislature and Governor on the following:

- Potential impacts of levee failures on water supplies derived from the Delta because of future subsidence, earthquakes, floods, and effects of climate change
- Options to reduce the impacts of these factors

- Options to restore salmon and other fisheries that use the Delta estuary (DWR and California Department of Fish and Game, 2008)

The bill amends Section 139.2 of the Water Code to read: “The department shall evaluate the potential impacts on water supplies derived from the Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta”:

- Subsidence
- Earthquakes
- Floods
- Changes in precipitation, temperature, and ocean levels
- A combination of these impacts (California Water Code Website, 2009)

DWR published the first report on Delta levee risks and options to reduce risks in January 2008 in compliance with AB 1200. This report relied heavily on the DRMS investigations and analyses.

Local and Regional Reclamation Districts and Maintenance Areas

Reclamation districts (RDs) are special districts organized under the authorizations granted by state law. They have most of the powers and restrictions that apply to other local public agencies; for example, compliance with the Brown Act requirements for public meetings and the requirement for a two-thirds approval by voters to raise taxes. RDs are primarily locally funded agencies responsible for the operation and maintenance of levee systems. RDs are allowed to use any of the following financing tools to raise funds:

- Special assessments based on the specific benefit each parcel receives from the improvements
- Fees or charges, including minimum and standby charges, for services provided
- User fees for the irrigation services provided to property owners
- The RD also may issue bonds to finance improvements (California Water Code Website, 2009).

RDs maintain a large network of agricultural drains and pumps and are responsible for interior drainage of many Delta islands. They maintain drainage channels and pump facilities.

Of the 1,115 miles of levees within the Delta, 730 miles are non-project levees (CALFED, 2000a). These levees are not part of the federal flood-control program and are maintained by local agencies, primarily RDs, that are partially reimbursed by DWR under the Delta Levee Subventions Program established in 1973. The Delta Flood Protection Act of 1988 significantly increased reimbursement opportunities, but also added a major environmental mandate to ensure no net long-term loss of habitat.

Operation and maintenance of non-project levees within the Delta are the responsibility of individual landowners and RDs. RDs are self-governing entities (not affiliated with the federal Bureau of Reclamation) regulated by the Central Valley Flood Protection Board. These local districts receive local tax funding to pay for levee maintenance. Standard practices used for maintaining the levees differ between districts and agencies, as does the amount of funding provided to perform these activities. Improvement and maintenance of these levees are challenging because of poor foundations and regulations to protect levee wildlife habitat (DWR, 1995).

The mission and purpose of RDs are to operate and maintain the levees surrounding the RD and to operate and maintain the internal drainage system to remove agricultural and urban runoff (RD 1000, 2010).

Services and facilities that can be financed by an RD include all things "necessary and convenient" to reclaim the land. Items commonly financed by RDs include facilities and services for sewage and waste removal, and facilities used for irrigation of lands inside or outside the district (RD 784, 2009).

The six counties that have lands within the Delta, as well as cities and special districts, are engaged in activities to reduce the risk of flooding. Activities may include construction, operation, and maintenance of structural features such as levees, and nonstructural activities. Nonstructural activities reduce property damage and loss of life and minimize economic impact in the event of a flood. These include floodplain zoning, enforcement of building restrictions in FEMA-designated regulatory floodplains, flood warning and evacuation plans, and flood proofing and relocation assistance.

Regional Flood-control Agencies

The Sacramento Area Flood Control Agency (SAFCA) is a regional agency charged with flood risk reduction to the City of Sacramento, other portions of Sacramento County, and portions of Sutter County. SAFCA's flood-control system features include levees along the Sacramento River that protect Natomas and Sacramento, levees on the American River in Sacramento, and levees and floodwalls along the South Sacramento County Streams Group. SAFCA partners with the Central Valley Flood Protection Board and the USACE on flood protection projects. SAFCA is partnering on the American River Common Features Project, which is strengthening levees on the American and Sacramento rivers to reduce flood risk to the City of Sacramento. SAFCA is also partnering with the State and the USACE on construction of an auxiliary spillway at Folsom Dam (SAFCA, 2009).

The San Joaquin Area Flood Control Agency (SJAFCA) is responsible for flood protection for the City of Stockton and San Joaquin County. In 1998, it completed the Flood Protection Restoration Project, which consisted of improvements to levees, floodwalls, and channels that removed most of the City of Stockton from the FEMA 100-year flood zone (USACE, 2008).

The West Sacramento Flood Control Agency (WSAFCA) is a Joint Powers Authority (JPA) created in 1994 through a Joint Exercise of Powers Agreement by the City of West Sacramento, RD 900, and RD 537. WSAFCA was established to coordinate the planning and construction of flood protection facilities within the boundaries of the JPA and to help finance the local share of flood control projects. The formation of this agency was primarily in response to authorization of the flood-protection repairs recommended in the Sacramento Metropolitan Area General Reevaluation Report. WSAFCA formed an assessment district in 1995 to fund the local cost share of these repairs.

Emergency Response

The scope and complexity of emergency management operations in the Delta are sufficiently different from flood risk to warrant a separate and focused white paper. Section 85305 of SBX7 1 states:

> *"(a) The Delta Plan shall attempt to reduce risks to people, property, and state interests in the Delta by promoting effective emergency preparedness, appropriate land uses, and strategic levee investments. (b) The council may incorporate into the Delta Plan the emergency preparedness and response strategies for the Delta developed by the California Emergency Management Agency pursuant to Section 12994.5."*

Based on this statutory requirement, an independent white paper on the topic of Emergency Response is under development for presentation to the Delta Stewardship Council in November. This separate white paper will provide an update on the Cal EMA efforts under Senate Bill 27, supported by the Delta Protection Commission's initial work on a multi-agency, collaborative multihazard emergency response strategy for the Delta.

Section 5
Future Issues

Delta levees are widely regarded as vulnerable as described in Section 3. These vulnerabilities have major implications for the Delta's future. Such vulnerabilities are often discussed quantitatively in terms of risks. In analyzing risks, risk is usually defined as the "probability of failure multiplied by the consequences of failure." This definition recognizes that similar failure events of equal probability are not necessarily equally risky. For example, when a large-diameter natural gas pipeline located in an isolated rural area has the same probability of failure as one located in an urban setting, the urban pipeline is more risky because of the greater potential consequences—higher potential for loss of life and extensive property damage.

Both of these two elements of a risk calculation can be very difficult to estimate. For most risk calculations, however, better tools are available for estimating the probability of failure than the consequences. The probabilities of levee failures are difficult to estimate because of the many different factors and the complex relationships that lead to an analysis conclusion of "failed" or "not failed." However, calculating the consequences of a given failure event is even more difficult. Several analyses have been performed addressing parts of the risk calculation for Delta levees and their findings are summarized below.

Present Risks

Because risks change over time, the present is an interesting point for beginning a discussion of risks. The Delta Risk Management Strategy (DRMS) selected a base year of 2005 and developed risk information for that year. It is adopted here as a practical definition of the present.

In the Delta risks have changed over time and are still changing. In the early 1900s the levees were quite low in height and the "islands" were more like real islands; subsidence had not yet created such a pronounced "bowl" effect. Now the levees are much taller, often in the range of 15 to 25 feet because the ground surface is much lower because of subsidence. Where the levees have not been substantially improved, the old configurations have become less stable and thus present a higher likelihood of failure. Since the land and improvements and the costs of recovery have increased, the consequences of failure are also larger. Today, Californians also rely more on the Delta for water supply, and the Delta ecosystem is becoming increasingly fragile.

There have been four major studies that have looked at various types of risks relative to Delta levees:

- Seismicity Hazards in the Sacramento-San Joaquin Delta, DWR, 1980
- Seismic Stability of Delta Levees. DWR, 1992
- Seismic Vulnerability of the Sacramento-San Joaquin Delta Levees, CALFED, 2000
- Delta Risk Management Strategy, Executive Summary, Phase 1, DWR, 2009

All have come to similar conclusions. The Delta levees face unusually high risks because they are situated on poor foundations, they were build in an ad hoc manner using nearby materials that were often unsuitable, and they were built before the use of careful design and construction procedures, especially regarding compaction and seismic response. The stresses on the levees have increased over time as the landward ground surfaces subsided and the heights of the levees correspondingly increased.

The latest of these studies, DRMS, considered all the hazards that confront the Delta levees, including floods, earthquakes, and sunny-day (high-tide) conditions. The Executive Summary prepared by DWR (2009) states:

> "Phase 1 of the DRMS analysis concludes that under business-as-usual practices, the Delta Region as it exists today is unsustainable…."

The DRMS work has provoked considerable confusion and criticism. The original draft report was extensively revised to clarify the analyses (URS/JBA, 2008) and was then peer reviewed. A formal peer review was conducted by an Independent Review Panel of the CALFED Science Program (now the Delta Stewardship Council's Delta Science Program). The Review Executive Summary concluded that "…the DRMS analysis is now appropriate for use in Phase 2, and is now acceptable for use as a tool for informing policy makers and others regarding potential resource allocation and strategies to address risk in the Delta Region…" (CALFED, 2008).

Another review was conducted by the Sacramento District of the USACE – focusing on seismicity and climate change. The USACE accepted the DRMS analyses on these two topics (USACE, 2010).

In the following sections the available information on the various risks from multiple sources is summarized.

Floods

FEMA is a primary source of present flood risk information. This agency administers for the NFIP, created in 1968 in response to the damage caused in the New Orleans area by Hurricane Betsy (see FEMA, 2010a). A key element of the program uses Flood Insurance Studies to produce Flood Insurance Rate Maps (FIRMs). The maps show Special Flood Hazard Areas (SFHAs) – areas that have been indicated as subject to inundation by a 1 percent annual chance flood (sometimes called a 100-year flood). SFHAs include areas described as "A" zones, or areas where mortgage lenders generally require purchase of flood insurance and there may be future building limitations. Areas not in the "A" zones generally are less likely because of ground elevation or protection by a certified levee or other protective feature. It may be advisable to purchase flood insurance to protect against "residual risk." This is because the 100-year flood is not a safety standard, but an insurance standard; the cost of insurance outside of an "A" zone is generally less than within an "A" zone.

In 2006, FEMA initiated a nationwide Flood Insurance Rate Map Modernization Project (see FEMA, 2010c). This includes a strict review of levees protecting low-lying areas in order to ensure that they meet FEMA criteria that are required for mapping a protected area as not being in a SFHA; that is, not subject to inundation by a 1 percent annual chance flood. Most areas of the Delta that were previously indicated as "protected" by "FEMA levees" (and therefore not included in SFHAs) are having difficulty proving that their levees are adequate. Some areas are initiating upgrade projects, such as West Sacramento and

Reclamation District 17 (Lathrop). For the most part, these areas are urban areas on the outer edges of the Delta. Revised FEMA maps are being issued over several years.

FEMA maps indicate that much of the central Delta, essentially all of the non-urban Delta, is within SFHAs and considered to be subject to inundation by the 1 percent annual chance flood. The urban areas at the edges of the Delta (West Sacramento, Sacramento, Stockton, Mossdale, etc.) are working to preserve their levee accreditation and thereby avoid being indicated as "A" zones.

The State has also begun a major initiative over the past 5 years to address flood risks. This began with a DWR "White Paper," *Flood Warnings: Responding to California's Flood Crisis* (DWR, 2005). The Executive Summary states:

> "While flooding has always been an unfortunate fact of life in many parts of California, the need for adequate flood management is more critical now than ever before. California's Central Valley flood-control system is deteriorating and, in some places, literally washing away. Furthermore, the Central Valley's growing population is pushing new housing developments and job centers into areas that are particularly vulnerable to flooding…."

A version of these "flood crisis" statements is also true for the Delta, which is the confluence area for all Central Valley floodwaters and the route these waters must use in exiting the Central Valley to San Francisco Bay and the Pacific Ocean. Much work has been performed to maintain and strengthen Delta levees resistance to floods over the past 25 years and much of the "deterioration" has been stopped or reversed. But still, the level of flood protection provided by Delta levees is low and often less than warranted, especially when considering that low-pressure surge and winds often occur at the times of high flood flows.

A major result of the DWR "White Paper" was passage of two major bonds in 2006 (Propositions 84 and 1E) with funding to upgrade the planning, flood management, and the flood-control facilities in the State, particularly in the Central Valley, including the Delta. The bonds provide approximately $4.9 billion for flood-risk reduction.

A second major result was the 2007 legislation package, "…a cooperative effort involving the State, members of the Legislature, local governments and planning agencies, landowners and developers…," undertaken to respond to the crisis described in the white paper and to apply the new funding. These bills include Senate Bills 5 and 17 and Assembly Bills 5, 70, and 156. An additional bill, supplementing the package (AB 162), was also passed in 2007 and requires "additional consideration of flood risk in local land use planning throughout California." A recent DWR publication (DWR, Undated) summarizes this legislation.

These initiatives are now being implemented by DWR through its "FloodSAFE California" program, including Central Valley Flood Management Planning, an "Early implementation Program" for flood system improvements, especially in urban areas, and continuation (with increased funding) of the Delta Levees Subvention and Special Projects Programs. Many of the FloodSAFE activities are midway in implementation and do not yet have definitive documents that estimate present and future flood risks. However, the following information is available:

- **Best Available Maps**. One of the DWR products responsive to the flood legislation is the collection of Best Available Maps of the 100- and 200-year floodplains using information available from earlier studies. The maps were required to be available by July 1, 2008, by SB 5 and are available on the Internet (DWR, 2010a). Maps are available for the entire Delta. An example is shown in Figure 5-1 (DWR, 2010b). In general, almost all the nonurban Delta is shown to be part of the present 100-year floodplain. Although the maps use the FEMA FIRMs available at the time, many of those maps were being revised based on FEMA's map modernization program. In many cases, the Best Available Maps were able to use other data to anticipate the expected revisions (for example, the tan areas in Figure 5-1). They also provide information on 200-year floodplains to the extent available (see the rose-tinted areas north of Rio Vista). The maps also indicate project and non-project levees differently (project levees have the red and yellow lines).

- **Levee Flood Protected Zones.** A second DWR product is a set of maps showing Levee Flood Protected Zones. These maps "estimate the maximum area that may be inundated if a project levee fails when the water surface elevation is at the top of a project levee." Figure 5-2 shows the Delta portion of the Sacramento River Basin map that presents Levee Flood Protected Zones (DWR, 2010c). Figure 5-3 shows the Delta portion of the San Joaquin River Basin (DWR, 2010d). Even though these areas have "protection" due to project facilities, they still have a "residual risk" because these facilities may be inadequate (the flood may be larger than the design flood) or the facility may fail for some other reason. Note that only areas protected by State-Federal project levees are shown. Some areas that are expected to flood, such as the Yolo Bypass, are not highlighted. Similarly, areas that are protected only by non-project levees are not highlighted. The legislation only required DWR to show areas protected by State-Federal project levees (the State Plan of Flood Control). Thus, the fact that an area is not highlighted does not mean it is adequately protected or will not flood. Therefore, many areas in the Delta are not identified because they are not protected by State Federal project levees.

Figure 5-1
DWR Best Available Map of 100- and 200-Year Floodplains
Source: DWR, 2010b

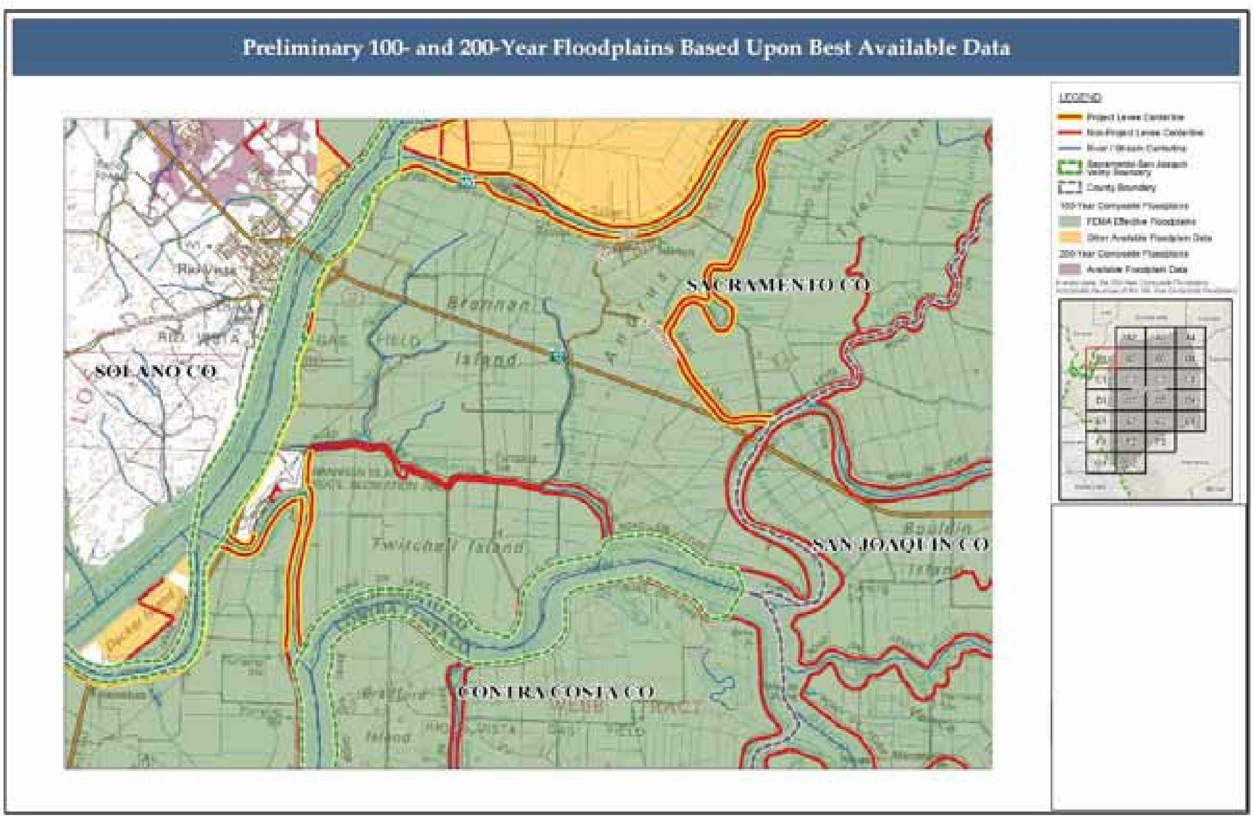


Figure 5-2
DWR Map of Levee Flood Protection Zones, Sacramento River Basin
Source: DWR, 2010c

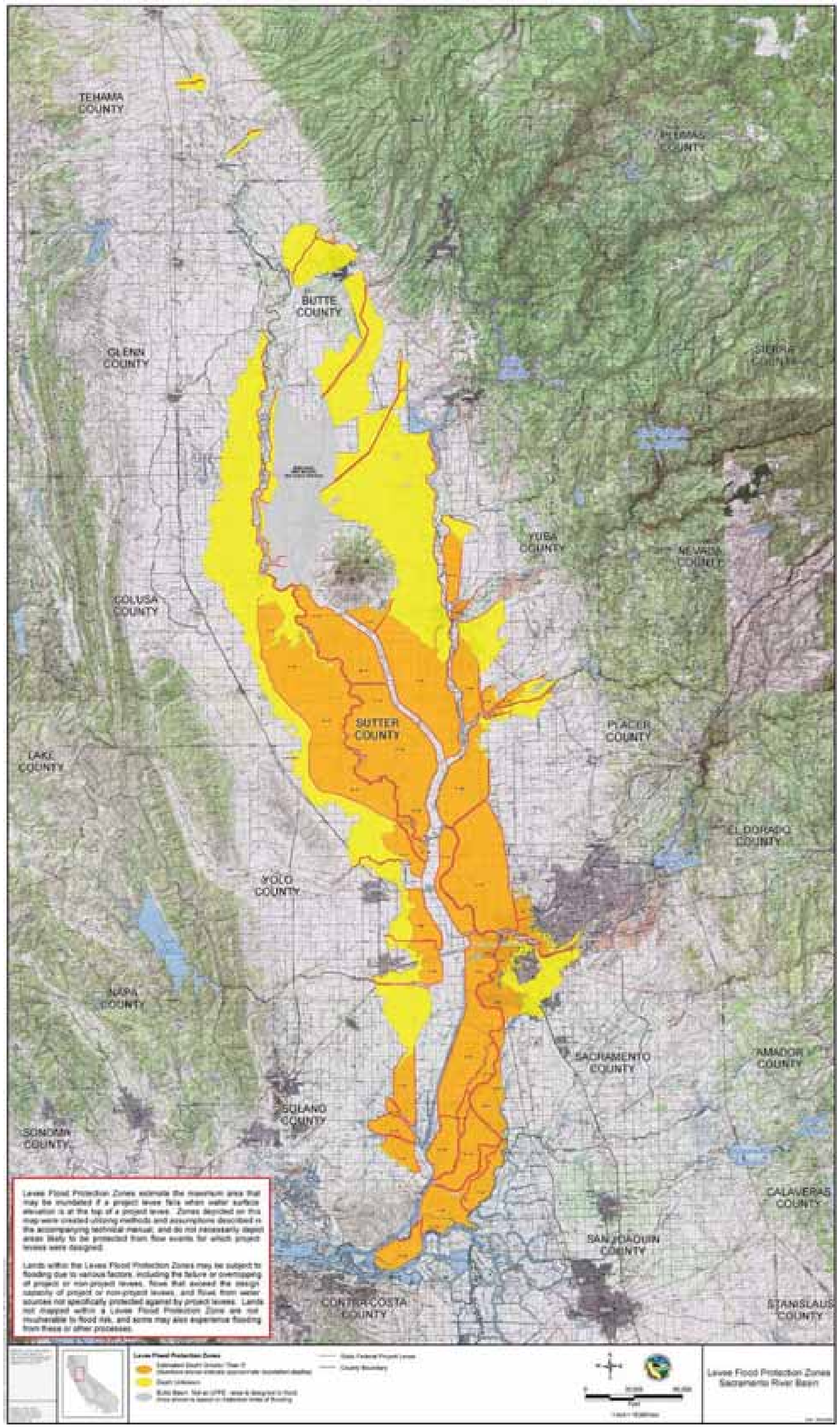
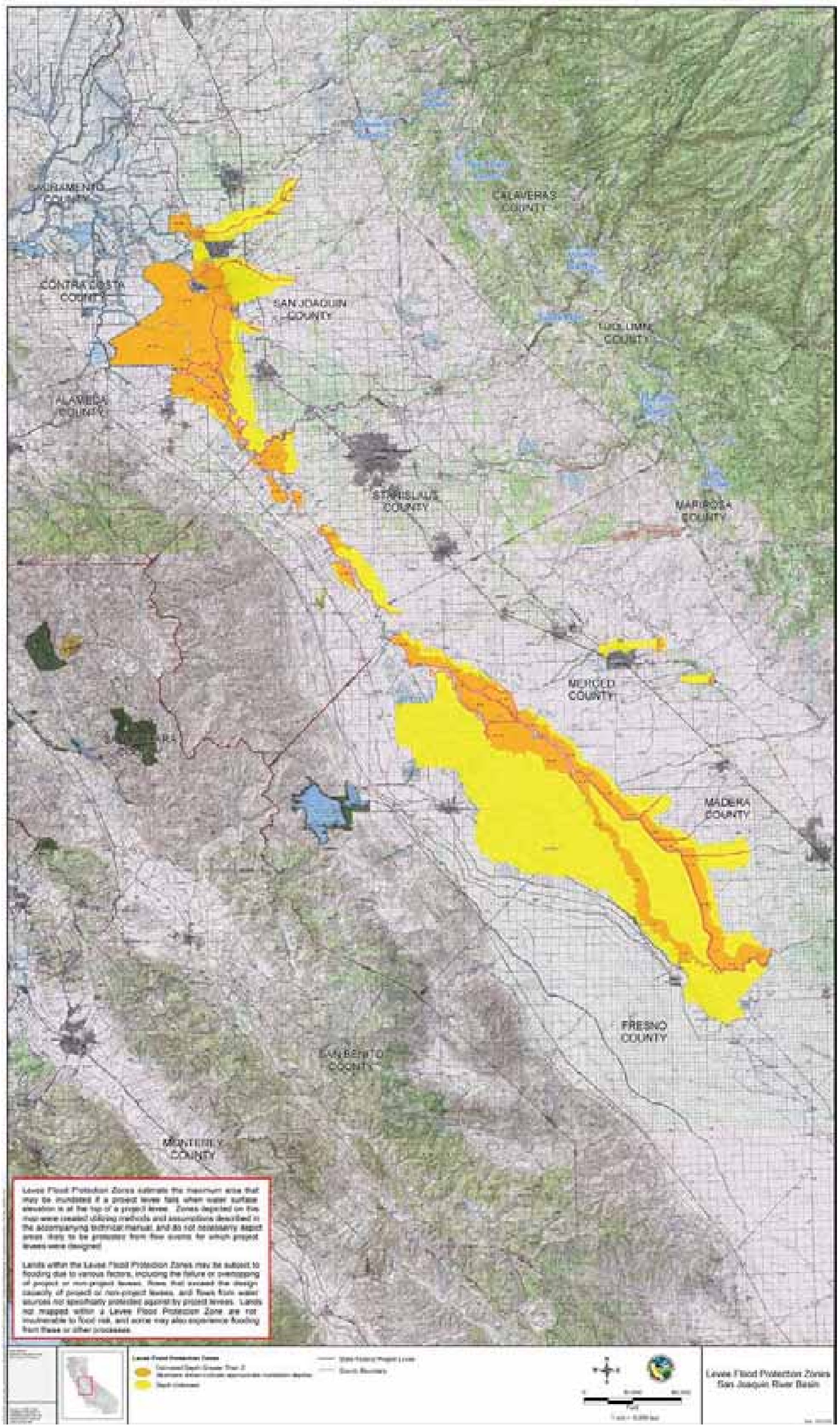


Figure 5-3
DWR Map of Levee Flood Protection Zones, San Joaquin River Basin
Source: DWR, 2010d



These maps are meant to communicate some information about the present risk of flooding for any small area in which people may be interested, such as their home. Clearly, the chance of flooding is high for an area indicated to be in a FIRM SFHA. The chance of flooding may be less in a levee-protected area that is not in a SFHA, but this "residual risk" is still real and something to be aware of and prepared for. It should be understood that although the 100-year level of flood protection is equivalent to having an annual chance of 1 percent of flooding in any one year, the risk builds with time. Over the life of a 30-year mortgage, the 100-year level of flood protection equates to a 26 percent chance of flooding (about 1 out of 4)—a relatively high risk.

To develop better information on flood and other levee risks, the DRMS considered the available information on the actual characteristics of Delta levees: their crest elevations, their geometry (height and slopes), and their embankment and foundation materials (URS/JBA, 2008). Using this information and many hypothetical floods, calculations were performed to see whether the levees might fail due to under-seepage, through-seepage, or overtopping. The result of this probabilistic analysis indicated about a 10 percent chance of annual flooding (10-year flood event) of up to four islands assuming a 50 percent confidence level. There was a 0.5 percent chance of annual flooding (200-year flood event) of up to 34 islands assuming the same confidence level.

A comparison of this result with what has occurred in past major floods for years after 1955 is shown in Table 5-1.

Table 5-1
Flows, Frequencies, and Delta-Suisun Islands Flooded in Major Historical Floods Compared with DRMS Estimate for 1% Annual Chance Flood
Source: URS/JBA, 2008

Water Year and Date	Peak Day Delta Inflow (cfs)[a]	Frequency Rating of Inflow[b]	Flood "Return Period"	Number of Delta Islands Flooded[c]
1986 (Feb 20)	661,272	0.028	36-year	8
1997 (Jan 3)	561,989	0.045	22-year	11
1965 (Dec 25, 1964)	470,122	0.075	13-year	2
1983 (Mar 4)	422,213	0.093	11-year	10
1995 (Mar 13)	387,177	0.112	9-year	1
DRMS median estimate	904,505	0.01	100-year	22 to 32

[a] URS/JBA, 2008, Table 7-9c
[b] URS/JBA, 2008, Table 7-5
[c] URS/JBA, 2008, Table 7-9b. Includes flooding of upland areas.

Note that the number of Delta islands flooded is not well-linked to the indicated flood as a cause. The data are not carefully enough documented to attribute cause or anything more that the approximate time. However, they do accurately show that 1983, 1986, and 1997 were the most damaging recent floods in terms of the number of Delta islands and tracts flooded.

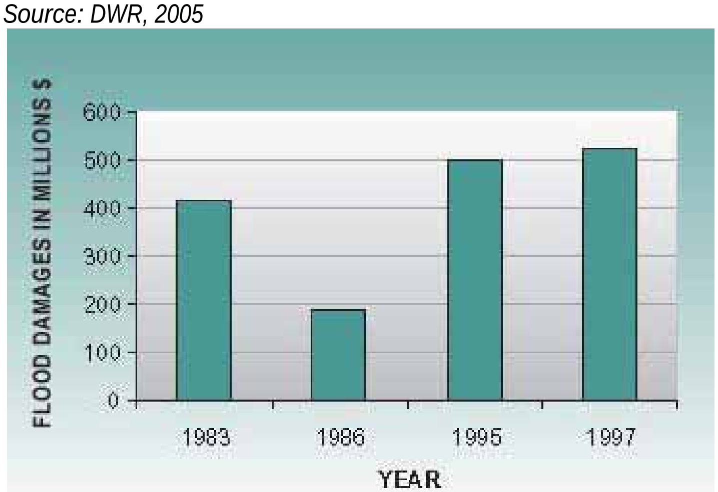
These numbers are quite variable. Also, the strength of many Delta levees has been changing (likely improving in some cases, deteriorating in others) over recent time. Tides may have been quite different during the various flood periods and may have affected island flooding. Some of these historical flood flows had only small contributions from streams other than the Sacramento River. Other floods had larger contributions from the San Joaquin, Cosumnes, or other streams (1986, 1997, and 1983). But the DRMS estimated peak flow for the present 1 percent flood is 37 percent higher than that seen in 1986, the highest inflow of recent record. It is reasonable to expect a significantly higher number of flooded islands than seen in these recent historical floods. But this is only about one-third to one-half of the islands that are not

FEMA accredited. So it indicates that, in such a flood, not all "vulnerable" Delta islands are expected to be inundated. The islands actually inundated may also include a few of the "levee-protected" islands shown on the maps described above. The islands actually flooded, and the actual total number will depend on many factors, including tides, presence of a low-pressure tidal surge, winds, flood-fight results, the distribution of flows among the various Delta tributaries, and anomalous conditions in the levees.

Clearly, however, Delta levees are more vulnerable to floods than FEMA NFIP accredited levees. Failures must be expected in large floods. Several factors contribute to these weaknesses including the lack of specific designs, the relatively low quality of construction materials and methods, their patchwork improvements, and their minimal freeboard.

The above discussion focused on the likelihood of flooding. There is less information available on the *consequences* of flooding, another element of the risk equation. DWR (2005) in their flood "White Paper" provided the information that the USACE has compiled on four of these five floods, but the flood damages are for the whole Central Valley, not just the Delta (see Figure 5-4).

Figure 5-4
Central Valley Flood Damages as Portrayed in DWR's White Paper
Source: DWR, 2005



Other data are likely to be available, but may be difficult to locate and interpret. For example, the 2004 Jones Tract levee failure is often discussed in terms of approximately $100 million of flooding damages, but the direct costs of repair may have been only about $25 to $30 million. This mainly indicates that flood damages (the consequences part of the risk formula) associated with property damage, crop losses, infrastructure impacts, and indirect economic losses are difficult to estimate, and numbers are often compiled using different rules.

DRMS made flood-consequences estimates to calculate year 2005 risks for the many scenarios it examined for potential loss of life and economic consequences (costs and impacts). Economic costs are the net costs to the state economy without any consideration of who within the state bears that cost. Economic impacts include a variety of other economic measures, including the value of lost output, lost jobs, lost labor income, and lost value added. These measures are not additive with each other, and the impacts should not be added to economic costs. Note that the range of estimates of potential flood consequences is quite broad. The estimated present costs for the Delta area from a 1 percent annual chance of flooding is indicated to be between $9 and $37 billion. Damages depend on the time of year, exactly which islands flood, and many factors difficult to project. Similarly broad ranges of estimates are indicated for economic impacts and loss of life. The estimated loss of life of the 1 percent annual chance flood is approximately 80 to 300 people. These broad ranges reflect the imperfect tools presently available for estimating economic costs and impacts and potential loss of life and also that the uncertainties in estimating the likelihood of failures have been magnified.

Although DRMS attempted to provide assessments of ecosystem impacts, these were less successful. Mechanisms for causing impacts to various species (especially threatened or endangered species) were identified for fish, aquatic and terrestrial vegetation, and terrestrial wildlife. It was clear from the work performed that levee breaches in floods can be disruptive to sensitive species. More specific general statements on fish impacts were not possible. Significant concerns were identified with impacts to native tree habitat and with losses of sandhill crane foraging habitat.

Earthquakes

The risks of earthquakes causing levee breaches and island inundations in the Delta have long been recognized. A DWR (1980) report begins:

> "There is a long history of levee failures in the Delta that have resulted in extensive economic damage, but no failures of Delta levees are known to be directly attributable to earthquakes. Even so, two factors indicate a possible bleak picture for the future of many Delta levees. First, no serious causative quakes have occurred on the nearby major faults since the San Francisco earthquake of 1906. Second, the Delta levees of today are vastly different than those in the 1906 Delta, which had limited size and extent."

These statements are still true today. And they are reinforced by 30 years of progress in seismology, earthquake engineering, and data gathered on the embankment materials and foundations of the Delta levees. For example, DWR (1992) estimated that a 43-year earthquake could cause moderately high damage to levees in the western Delta, and low to moderate damage in the central Delta (see Figure 5-5). However, for a 300-year earthquake, most of the levees in the central Delta would be expected to experience moderately high damage.

CALFED (2000) provided a more detailed assessment of the "Seismic Vulnerability of the Sacramento–San Joaquin Delta Levees." It concluded that "…an earthquake with a 100-year return period is predicted to cause 3 to 10 levee failures in the Delta…." and that a 300-year earthquake could cause between 5 and 45 levee failures. This study indicated that levees on Sherman Island and in the central Delta were particularly at risk.

Figure 5-6 (DWR, 2009) shows the faults now recognized in the San Francisco Bay and Delta areas. Much more detail has been developed since 1980. The quiet period relative to earthquake activity noted in the 1980 report has largely continued as shown in Figure 5-7 (WGCEP, 2003). The M6.9 Loma Prieta earthquake in 1989 has been the only Bay Area earthquake of significant magnitude since 1906, and it was far enough away that it did not cause noticeable damage in the Delta. (Although some refer to the Loma Prieta Earthquake as a Bay Area earthquake, it was not; it was a Santa Cruz area earthquake and over 50 miles away from the southern edge of the Delta.)

One of the reasons why the Delta appears to have never experienced an earthquake-induced levee failure is because the modern Delta levees have never experienced a significant level of earthquake shaking. As previously noted, the 1906 San Francisco Earthquake is believed to have relieved much of the tectonic stress in the region over the last 100 years or so. However, as illustrated by Figure 5-7, it is believed that the faults have been building strain during the quiescent period, and a rejuvenation of the higher level of earthquake activity that was present in the Bay Area prior to construction of the modern Delta levees may be likely. The figure, developed in 2003 by the United States Geological Survey, estimated a 62 percent probability of a M6.7 or greater earthquake in the Bay and Delta Area within 30 years (WGCEP, 2003).

Figure 5-5

Estimated Damage to Delta Levees from a 43-year Earthquake

Source: DWR, 1992

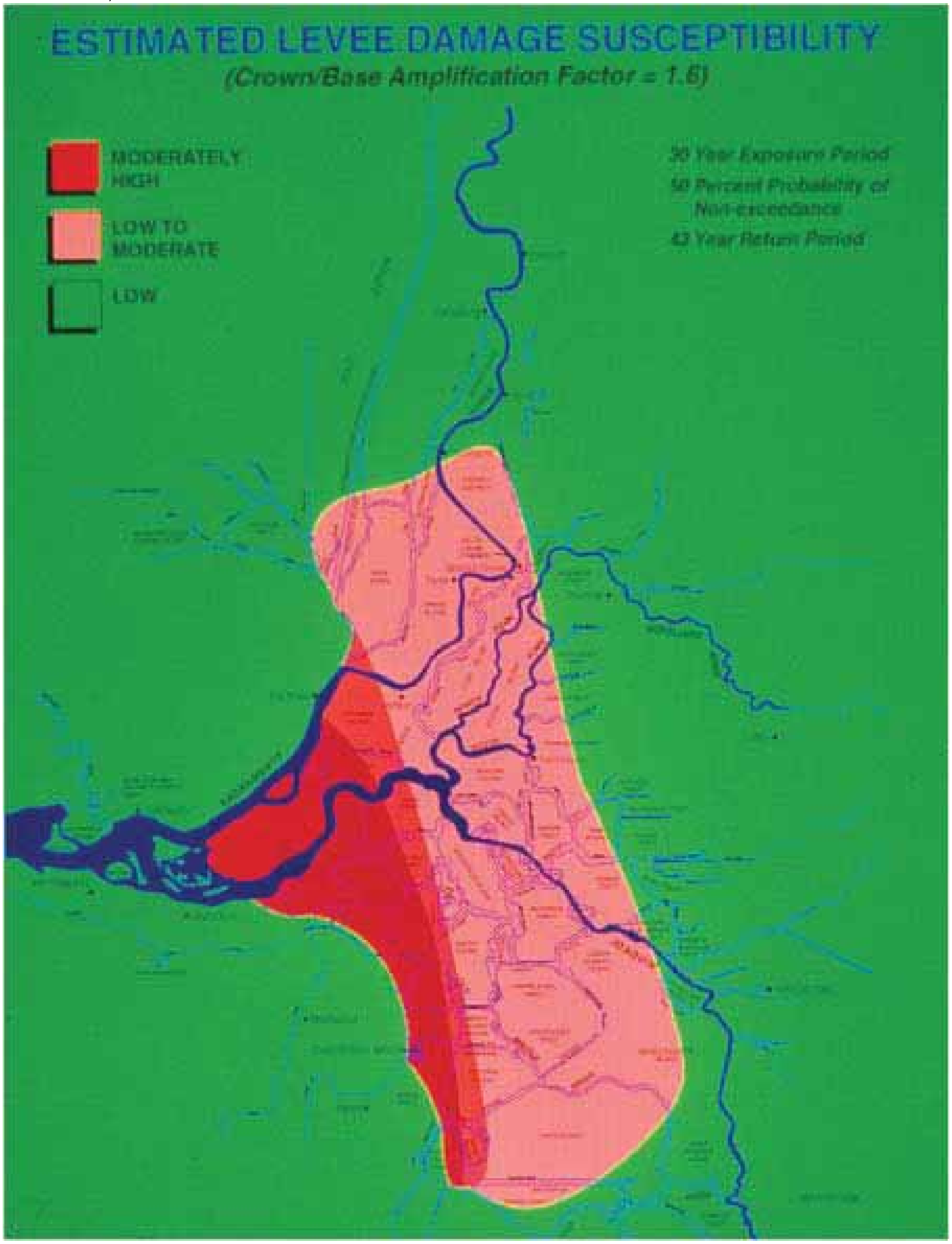


Figure 5-6
San Francisco Bay and Delta Area Earthquake Faults
Source: DWR, 2009

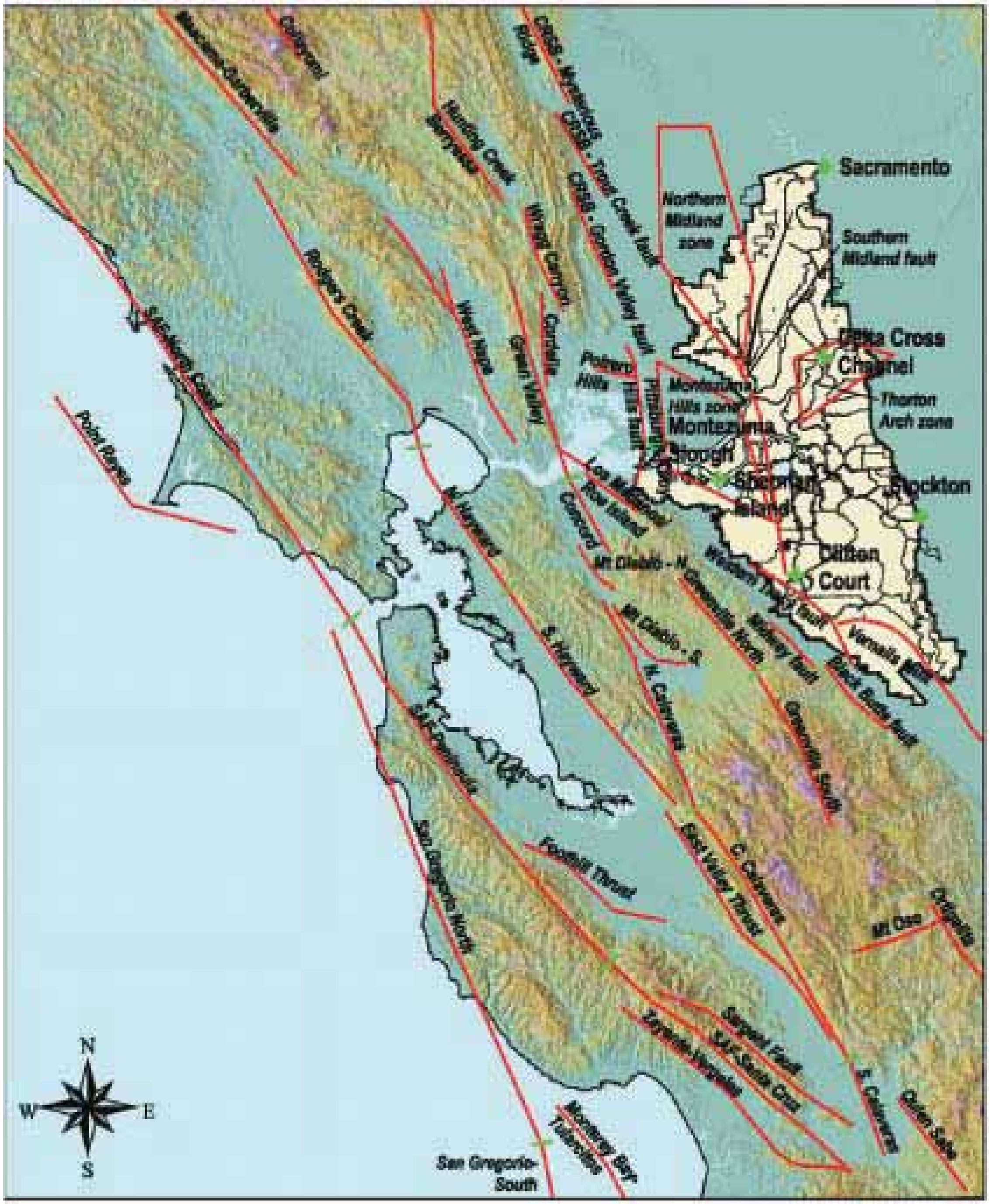
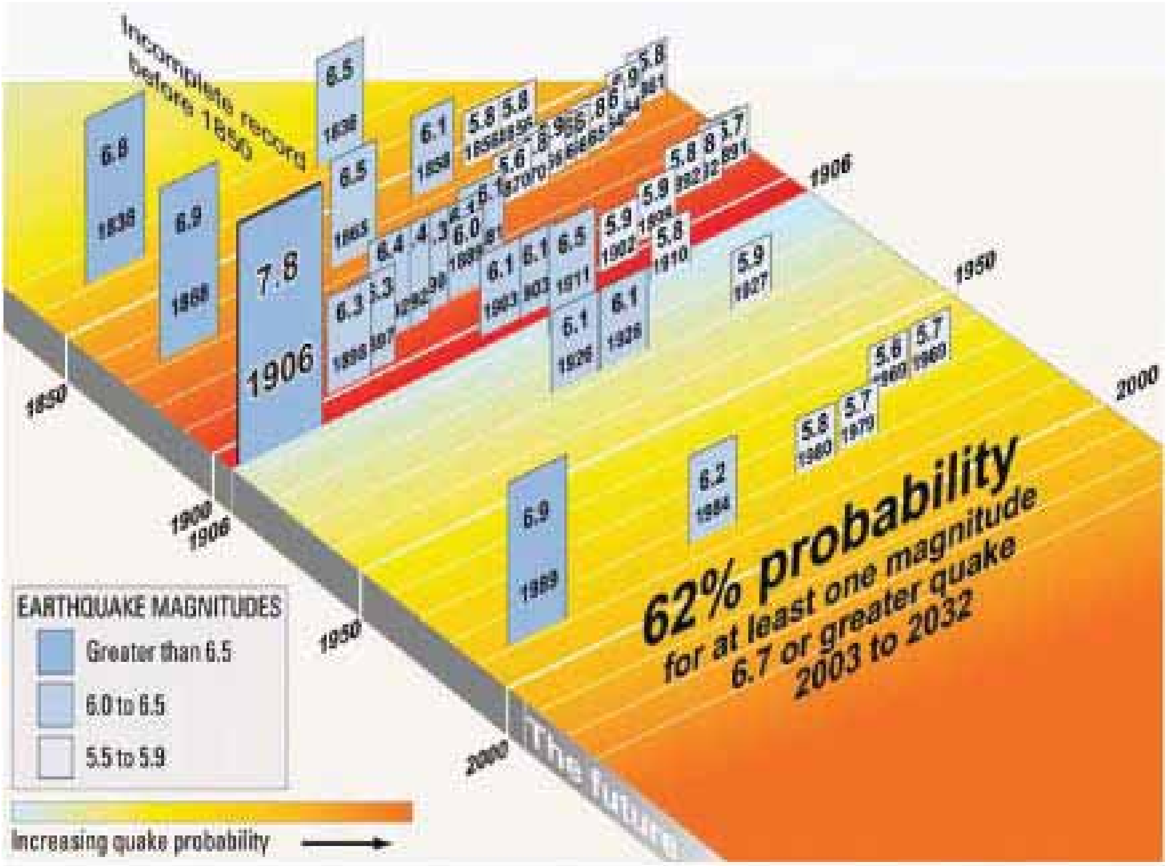


Figure 5-7
Temporal Perspective on San Francisco Bay and Delta Area Earthquakes and Changing Earthquake Probability
Source: WGCEP, 2003



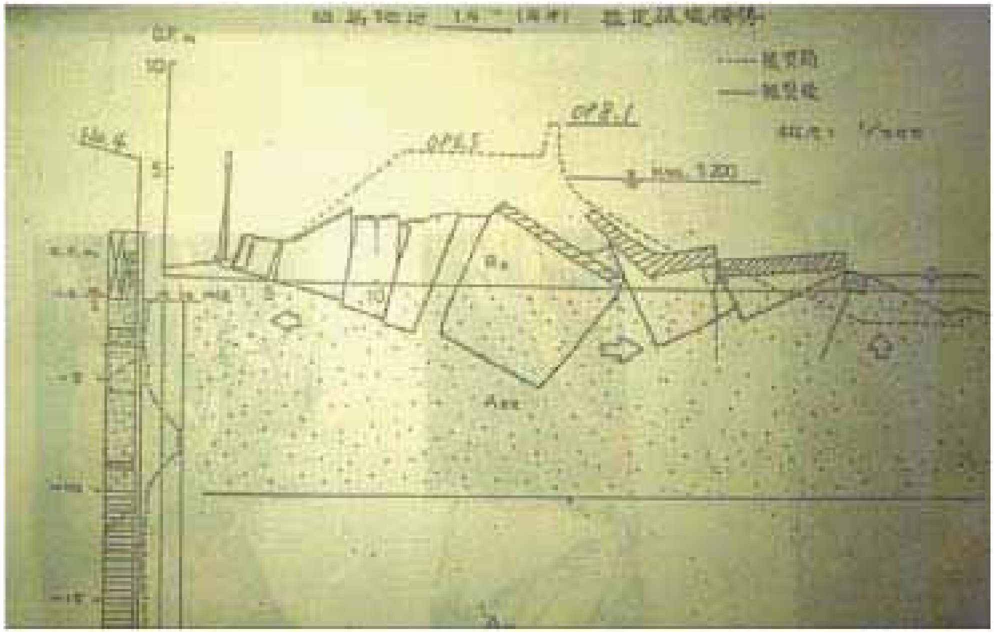
A key consideration in assessing the present potential for seismic failure of Delta levees is the potential mode of failure. Delta soils are commonly marsh deposits (peat, silt, and clay) intermixed with or often overlying sandy deposits of stream sediments. Usually, Delta levees were built on the marshy soils without foundation preparation or improvement. Over time, all types of soil types were used to build levee embankments that were not well compacted. The embankments can have large areas of loose sandy soil, and the marsh-soil foundations may overlie loose to medium-dense sands. Thus, either the levees or sublayers of their foundations can be sandy, unconsolidated, saturated materials that are susceptible to liquefaction during seismic shaking. Figure 5-8 provides an example of levee failure due to liquefaction. The Yodo River Levee in Japan collapsed as a result of the 1995 Kobe earthquake. The cross section of the collapsed levee is shown in Figure 5-9; note that the surface on which people are walking in Figure 5-10 is approximately 5 meters (16.4 feet) lower than the top of the wave wall and about 2 meters (6.6 feet) below the indicated high water level. This situation is analogous to what might occur with shaking the Sacramento River levee in the northern Delta (if it contained or was built on sandy materials), assuming dry season flows. If the collapse occurred during high flows, or if a flood occurred soon after the earthquake, inundation of the protected area would be expected. In the tidal reaches of the Delta, where levees must hold water out of protected areas every day, island inundation would be likely to occur immediately.

A railroad embankment in the Suisun Marsh belonging to the Southern Pacific Railroad suffered extensive damage and partially sank into its foundation during the 1906 earthquake. This damage is presumed to have occurred in the Suisun Marsh and not in the Delta because the Suisun Marsh is closer to the earthquake fault rupture and experienced much stronger shaking.

Of course, liquefaction is not the only mode of seismic failure. Overly steep waterside levee slopes were identified as another potential weak feature that can lead to instability in the context of an earthquake. However, most engineering assessments in the Delta have concluded that levee and foundation liquefaction are the most dominant potential modes of failure.

Figure 5-8
Collapsed Yodo River Levee Due to the 1995 Kobe Earthquake
Source: URS/JBA, 2008

Figure 5-9
Cross Section of the Liquefaction-collapsed Yodo River Levee
Source: URS/JBA, 2008



Figures 5-10 through 5-13 provide additional views of liquefaction damage to levees and similar embankments due to earthquakes.

Figure 5-10 shows levee damaged by the Imperial Valley earthquake in May, 1940. Note that the levee crest has dropped 7 feet and has extensive crevasses and cracking due to its almost complete sinking into its foundation.

Figure 5-11 shows a road embankment/levee at Moss Landing that failed due to the Loma Prieta Earthquake in October 1989.

Figure 5-12 shows the failed Sheffield Dam, which was an earth embankment similar to a levee that liquefied and failed during the 1925 Santa Barbara Earthquake.

Figure 5-13 shows image of the failed Niteko Dams, which were earth embankments similar in size to levees that liquefied and failed during the 1995 Kobe Earthquake.

In the Delta, the peaty and organic soils are presumed to be unlikely to liquefy and lose significant shear strength. Rather, it is the sandy and silty soils in either loose levee fills, or in foundation layers beneath the organic soils that are of a concern for liquefaction. In some areas, notably the south levees of Sherman and Twitchell islands, the levees are commonly composed of very loose and saturated sandy soils and are believed to be readily liquefiable. In other areas of the Delta, the levee embankments are composed of more clayey or dense soils and are not as liquefiable. Also, in many areas of the Delta, the foundation sands beneath the organic soils are moderately dense and not easily liquefied. However, there are other areas where the marsh deposits were eroded out by pre-reclamation channels that left behind loose mineral soil deposits that may be extremely liquefiable. In addition, there have been over 160 levee breaks over the last century. In most cases, levee breaches are believed to have scoured out much of the organic soils. These deep scour holes were then commonly backfilled with loose, hydraulically placed sands. Such soils are probably very liquefiable, so the past levee breach repairs represent potential weak spots in the Delta levee system. All of this combined results in a very heterogeneous and variable levee system wide a range of seismic vulnerabilities.

CALFED (2000) provided a more detailed assessment of the "Seismic Vulnerability of the Sacramento–San Joaquin Delta Levees." It concluded that "…an earthquake with a 100-year return period is predicted to cause 3 to 10 levee failures in the Delta…." and that a 300-year earthquake could cause between 5 and 45 levee failures. This study indicated that levees on Sherman Island and in the central Delta were particularly at risk.

Table 5-2 gives a summary of key conclusions from the nine different studies that have addressed Seismicity in the Delta region and considered the vulnerability of the Delta's levees. A consensus is apparent. The levees are seismically vulnerable and many islands are likely to flood in a significant earthquake.

Figure 5-10
Levee Liquefaction Damage Caused by the 1940 Imperial Valley Earthquake
Source: URS/JBA, 2008

Figure 5-11
Road Embankment / Levee Collapsed at Moss Landing in 1989 Loma Prieta Earthquake
Source: Seed et al., 1990

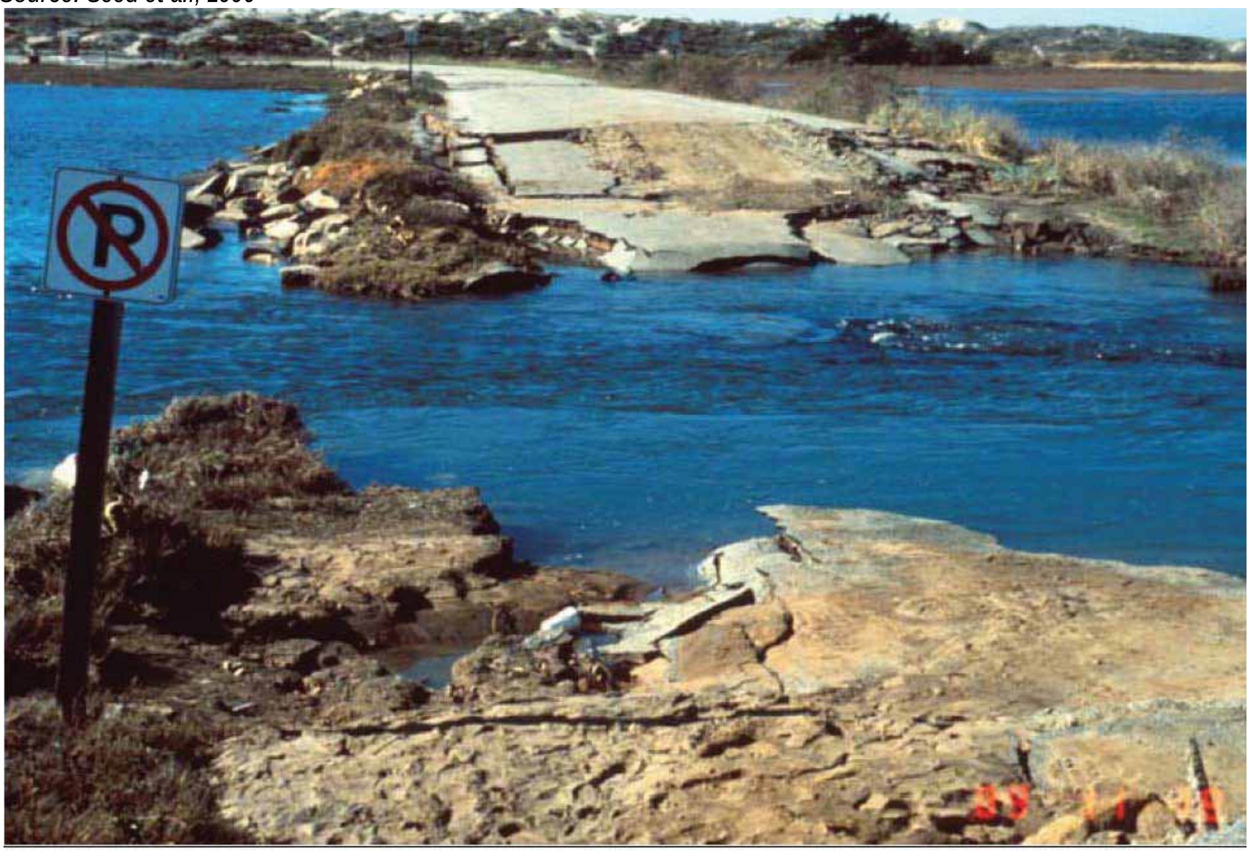


Figure 5-12
Failure of the Sheffield Dam
Failure mechanism similar to a levee that failed during the 1925 Santa Barbara Earthquake.
Source: Seed et al. 1990

Figure 5-13
Failure of the Niteko Dams Following the 1995 Kobe Earthquake
Source: Seed et al. 1995

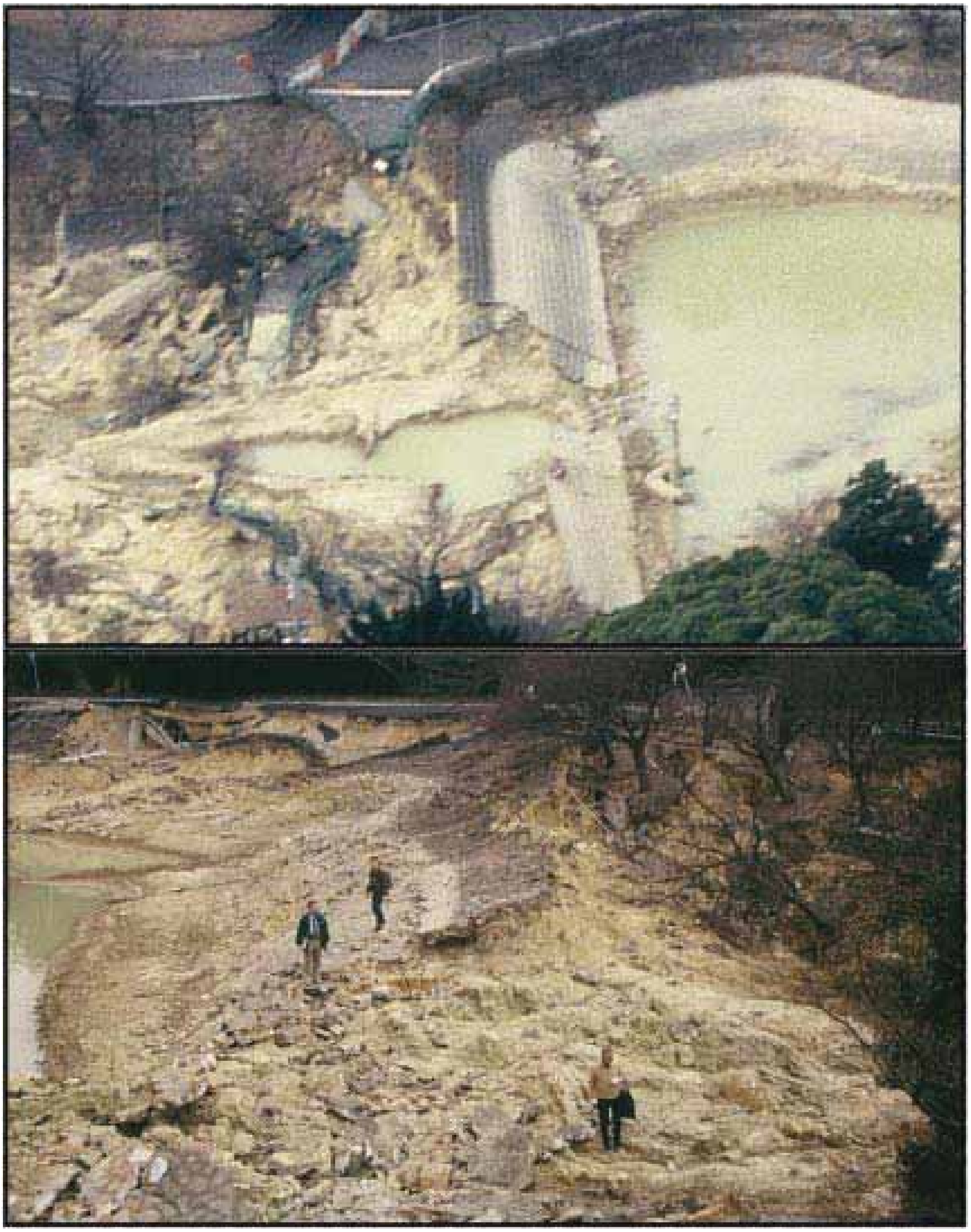


Table 5-2
Summary of Previous Studies on Seismic Vulnerability of Delta Levees

Investigation	Conclusions
Seismic Hazards in the Sacramento–San Joaquin Delta, DWR, 1980	“Available information strongly indicates that much of the levee system is susceptible to failure during a severe earthquake…” recommends further investigations.
Mokelumne Aqueduct Security Plan, Converse Ward Davis Dixon, 1981, 1982	“It should be noted that there have not been any major earthquakes affecting the Delta during the past 80 years. On the other hand, the Delta has been shaken severely at least three times during the 1800’s. Since only a few small levees or other man made structures existed at that time there is only a short list of damage accounts for these events. However, should similar seismic events occur at the present time, major portions of the delta are expected to be inundated…Significant lengths of levee at numerous locations around the perimeters of each of the islands and tracts along the existing aqueduct alignment can fail as a result of ground shaking in excess of 0.2g, which corresponds to the 100-year level of shaking…”
Sacramento-San Joaquin Delta Levees – Liquefaction Potential, Office Report, USACE Sacramento District, 1987	Of 37 Delta islands having geotechnical data to review, 8 islands were found to have high potential for earthquake-induced liquefaction, 14 islands found to have moderate potential, and 15 with low potential. “It is likely, however, that all islands which have a high potential for liquefaction will undergo levee damage significant enough to cause flooding of the island during a strong earthquake.”
Preliminary Seismic Risk Analysis for the Delta Water Management Study, Reclamation, 1989	Concluded that up to 35-40 percent of Delta levees would undergo failure for a 100-year exposure period due to liquefaction of levee and foundation materials, and levee deformation.
Preliminary Seismic Risk Analysis for the Delta Water Management Study, North Delta, Reclamation, 1991	Concluded that between 0 to 8 percent of the levees on the eastern portion of the North Delta all the way up to 31-36 percent of the levees on the western portion might fail due to earthquake shaking during a 100-year exposure period.
Seismic Stability Evaluation of the Sacramento-San Joaquin Delta Levees, DWR, 1992	Extensive areas of levee slumping and cracking and isolated reaches of levee failure could be expected within the central Delta, together with widespread levee failure in the western Delta for a 475-year earthquake. Results for 43-year earthquake also given.
Geotechnical Investigation – Earthquake Safety Assessment of the Mokelumne Aqueduct San Joaquin Delta Crossing, Summary of Findings, Earth Sciences Associates, 1992	A high potential for earthquake-induced liquefaction exists for half of the sites along the Mokelumne Aqueduct that were studied, with a moderate potential an additional quarter of the sites. Levee failures considered likely in many areas in the event of a strong earthquake. Additional information regarding the potential for earthquake motions to either amplify or attenuate in Delta soils was recommended.
Seismic Vulnerability of the Sacramento–San Joaquin Delta Levees, CALFED Bay-Delta Program, 2000	Estimated Delta levee vulnerabilities indicated that between 3 and 10 levee failures would occur during a 100-year earthquake and between 6 and 45 levee failures would occur during a 300-year earthquake. The investigation also concluded that attempting to significantly reduce seismic levee fragility will be both difficult and expensive, and that improved emergency response plans and preparedness had considerable merit.
Delta Risk Management Strategy, URS/JBA Consultants, 2008	See text

The most recent, comprehensive and sophisticated assessment of the likelihood of seismic levee failures in the Delta under present conditions was performed by DWR's DRMS project. The report (URS/JBA, 2008) used a probabilistic seismic hazard analysis (PSHA). Some of the key findings of the DRMS report are as follows:

- Levees composed of liquefiable fill are likely to undergo extensive damage as a result of a moderate to large earthquake in the region.
- Levees founded on liquefiable foundations are expected to experience large deformations (in excess of 10 feet) under a moderate to large earthquake in the region.
- At Suisun Marsh, the earthquake-induced deformations under strong shaking are large as a result of deep, very soft clay deposits forming at the levee foundation.

The results of the DRMS seismic vulnerability analysis are summarized in the Phase 1 Risk Analysis Report (URS/JBA, 2008). Figure 5-14 shows the 1 percent annual chance peak ground accelerations calculated for the Delta aggregated for all the faults considered and factoring in the attenuation of the shaking as the distance from the source increases. Although the DRMS analysis considered modes of failure other than liquefaction, the levee vulnerability was most pronounced for those levees susceptible to liquefaction. The analysis indicated about a 10 percent chance of annual flooding of up to two islands due to earthquakes (assuming a 50 percent confidence level.) There was 0.5 percent chance of annual flooding of up to 48 islands, assuming the same confidence levels.

This addresses the first part of the seismic risk calculation, the likelihood of failure. DRMS also estimated the present consequences of failure. The consequences included repair and dewatering costs, loss of use of flooded facilities, and the disruption costs associated with transportation routes and water exports. The calculated costs, economic impacts, and loss of life from seismic failures from a 1 percent annual chance earthquake would be 6 to 11 people, and the economic costs could be from $28 billion to more than $50 billion. As was the case with flood consequences, the tools for estimating consequences from seismic events are less well developed than the methods of analyzing the likelihood of failures. Economic impacts and loss of life estimates were made and are also indicated in the table. Ecosystem impacts were discussed, but were quite difficult to pin down because a whole variety of failure scenarios was considered and ecosystem impacts tend to be very dependent on the scenario. However the calculations do show that the consequences are expected to be significant. This leads to the overall conclusion that the present risks (likelihood of failures and their consequences) from the seismic vulnerability of Delta levees are substantial.

Day, High-Tide Risk

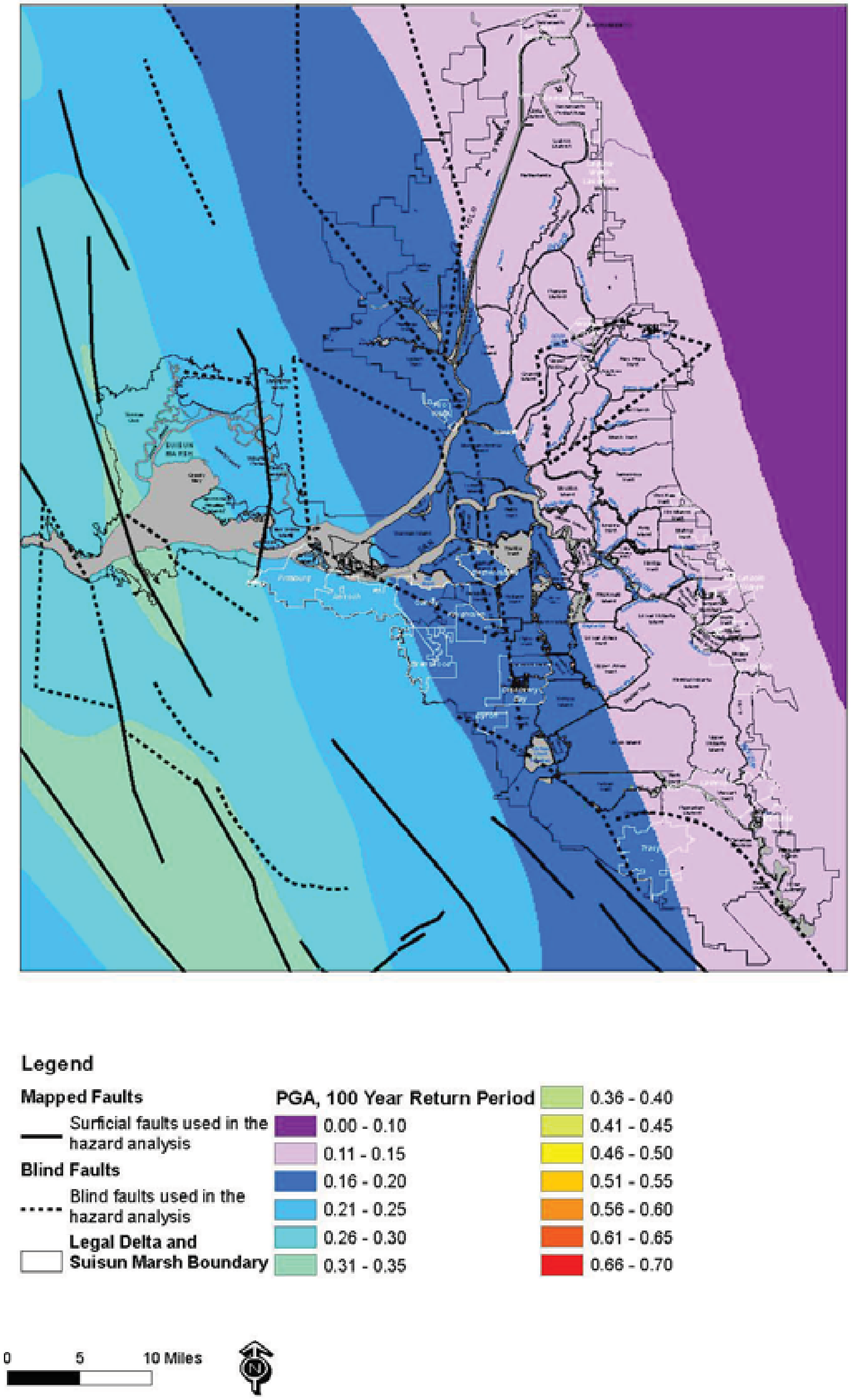
Delta levees can also fail under conditions that are not attributable to floods or earthquakes. These failures, that may occur on sunny days, but are usually associated with high tides, will continue sporadically. The DRMS study (URS/JBA, 2008) states:

> "Generally, these failure events may be the result of a combination of high tide and pre-existing internal levee and foundation weaknesses caused by burrowing animals, internal compounded erosion of the levee and foundation through time, and human interventions such as dredging or excavation at the toe of the levee."

The Jones Tract failure in 2004 is an example. Based on historical data, DRMS (URS/JBA, 2008) estimated that a Delta levee breach due to some factor other than a flood or an earthquake would occur approximately once every 10 years, or would have an annual frequency of occurrence of 0.1.

The consequences of a sunny-day levee failure will vary dramatically depending on which island fails and what improvements and infrastructure are impacted.

Figure 5-14
PGA Hazard for a 100-year Return Period



Aggregated Present Risks

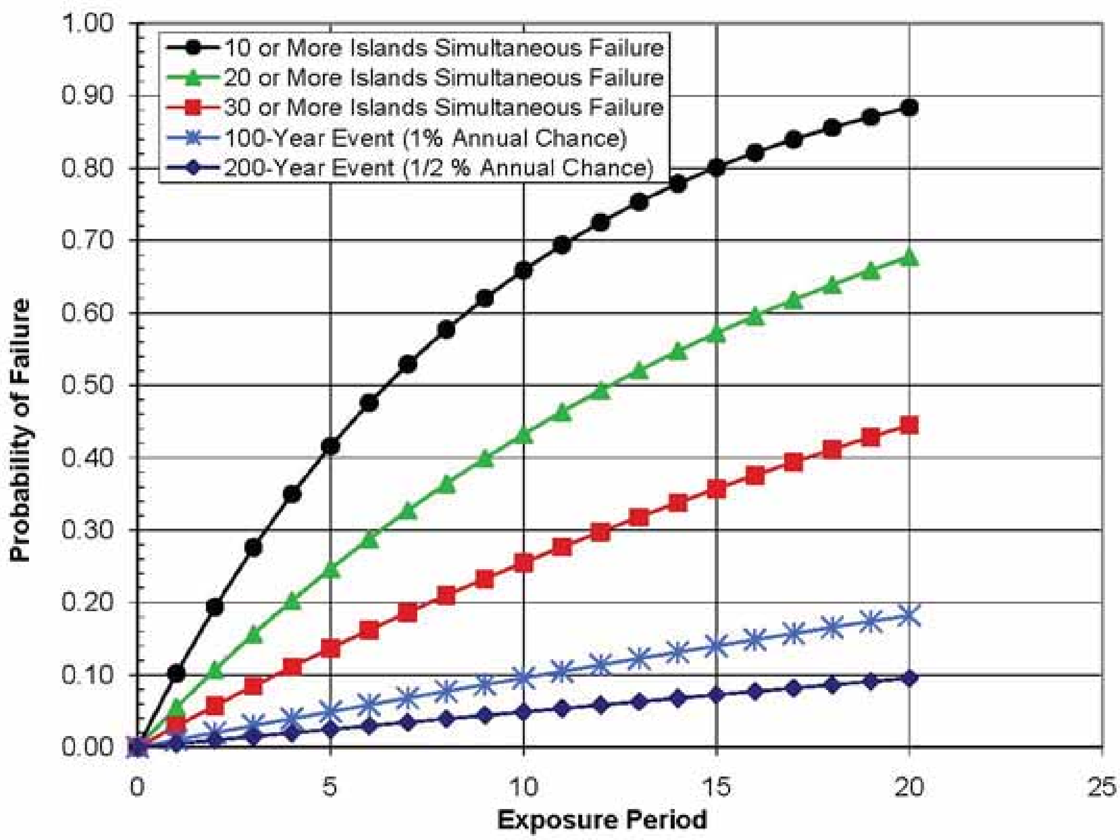
When considering present risks for the Delta as a whole, these flood, seismic, and other risks must be aggregated. DRMS tabulated of the aggregate annual frequencies for flooding several Delta islands simultaneously (URS/JBA, 2008). An annual chance of 5.5 percent for 20 or more simultaneous island inundations is indicated.

Aggregate Risk with Multiple Years of Exposure

The preceding discussion of risk has been restricted to an assumed annual exposure period: the chance of experiencing a given-sized undesirable event, such as a flood, within a single year. However, when one considers exposure to these risks for several years, the chances of experiencing at least one undesirable event is much higher. This is the same phenomenon as considering the exposure of a home to a 1 percent annual chance flood over the 30-year period of a typical mortgage; the chance of having at least one flood of that magnitude or larger is 26 percent.

Figure 5-15 shows the aggregate present risks of experiencing the 10, 20, and 30 island events assuming multiple years of exposure. Since only present (2005) risks are being considered, only a relatively short exposure period (20 years) is considered. The risks shown are very substantial and indicate that even if the numbers are off to some extent, the danger is very significant. They also do not account for the risk reduction that might be accomplished with enhanced emergency response, flood-fighting, and other risk-reduction efforts. Longer exposure periods should consider the ways in which annual risks are expected to change. That is addressed in the next section.

Figure 5-15
Failure Probability versus Exposure Period



Future Risks

It is important to consider whether risks are changing with time when considering risks over the long term. In the case of Delta levees, risks are changing and some are changing dramatically. The DRMS work (URS/JBA, 2008) addressed future risks in Section 14. Those findings will be summarized here, supplemented by other available information. The expected changes are discussed relative to the 2005 base year addressed in the previous section.

There are three broad types of changes that will affect how Delta levee risks evolve (URS/JBA, 2008):

- The changing landscape of the Delta due to climate change and subsidence
- The changing probabilities of natural hazard events, such as earthquakes and floods
- Other evolving exogenous factors, such as state, regional, and local population, local land use, economic activity, and ecosystem habitat and species affected by levees and levee failures

It will be necessary to consider time carefully relative to changing risk. More years mean more time for changes to accumulate and also a greater period of exposure to the risks.

Finally, it is necessary to recognize that this discussion addresses “business-as-usual”; it assumes that existing policies and management practices continue unchanged. Although this is unrealistic, other assumptions become difficult to justify, and business-as-usual can be useful as a reference point or baseline. Again, these risk estimates do not consider risk-reduction measures (such as levee improvements, emergency response, land use changes, and water export changes) that might be employed. These risk estimates and scenarios provide a base case that can then be used in evaluating such risk-reduction measures.

Drivers of Change for Delta Levee Risks

The “Status and Trends” document (URS, 2007) prepared for Delta Vision identifies the following “drivers of future change” for the Delta:

- Subsidence
- Global climate change – sea level rise
- Regional climate change – more winter floods
- Seismic activity
- Introduced species
- Population growth and urbanization

Although each of these factors has great relevance to the overall future of the Delta, they enter into an analysis of Delta levee failure risks in different ways. An instructive example is “introduced species.” When including this driver as a factor influencing the Delta’s future, the obvious thought is that introduced species may impact the Delta ecosystem by changing the viability of native species (such as delta smelt). When thinking of levee risks, however, two other modes of causation are primary considerations.

First, does the introduced species have some direct causative effect that either increases or decreases levee vulnerability? For example, the Chinese mitten crab received a great deal of attention several years ago because it burrows into levees, and there was concern that it would increase their susceptibility to failure. However, this seems to have been a false alarm; the burrowing activity was assessed to be only shallow and not detrimental to levee stability (Luster, 1998), and the population of mitten crabs in the Bay/Delta systems appears to have dramatically declined (Hieb, 2009).

Secondly, does a levee failure, or the simultaneous flooding of several Delta islands, have a significant effect (consequence) on some aspect of ecosystem viability, such as improving or decreasing the Delta's hospitability for an introduced species or increasing or decreasing the threat to an endangered species?

These are much more focused considerations than the overall "driver of change" label being considered when "introduced species" was placed on the list.

Table 5-3 is based on a similar table developed by DRMS (URS/JBA, 2008) to qualitatively characterize several more specific drivers of change related to Delta levees risks in future years.

Table 5-3
Directions and Apparent Magnitudes of Drivers of Change for Delta Levee Risks under BAU

Driver	Change to Likelihood or Consequence?	Increase or Decrease Levees Risk?	Large or Small Relative Change?
Sea level	Both	Increase	Moderate to large
Tidal amplitude	Likelihood or both	Not clear; increase?	Unknown; small/moderate
Storm surge frequency	Likelihood	Not clear; increase?	Unknown; maybe moderate
El Nino frequency	Likelihood	Not clear	Unknown
Inflow flood frequency	Likelihood	Increase	May be large to very large
Wind/wave events	Likelihood or both	Not clear; increase?	Unknown
Seismic frequency	Likelihood	Increase	Moderate
Subsidence	Both	Increase	Moderate to large
Seasonal runoff	Consequence	Increase	Moderate
Water supply yield	Consequence	Increase	Moderate
Water supply demand	Consequence	Not clear	Unknown
Delta area population	Consequence	Increase	Large
Delta land use/infrastructure	Consequence	Increase	Moderate to large
Delta area economic activity	Consequence	Increase	Moderate to large
Regional and state population	Consequence	Increase	Large
State economic activity	Consequence	Increase	Large
Introduced or lost species	May be either	Not clear	Unknown

Source: DRMS, 2008 Table 14-3

Three points are noted based on Table 5-3 and the related DRMS observations:

- For the six items that have uncertain impact as drivers (listed as "unknown"), part of the uncertainty is due to lack of an obvious significant impact. Although these items may ultimately be found to be important, better understanding must be achieved.
- Four items are expected to significantly increase the likelihood of Delta levee failures or require substantial strengthening of levees to avoid increased likelihood of failure. These are sea level rise, subsidence, inflow flood frequency, and seismic frequency. Two of them, sea level rise and subsidence, are also expected to increase the consequences of levee failures. They are discussed in the following sections.
- Six items are expected to cause moderate or large increases in the consequences of levee failures. Those items are more difficult to estimate for future years and to analyze for their effects on consequences, but they are discussed below.

More involved and detailed discussions of each driver of change are provided in the DRMS Phase 1 Risk Analysis Report (URS/JBA, 2008, Chapter 14).

Continued Subsidence

Relative to levees, it is important to distinguish between two different mechanisms of subsidence:

- Oxidation or other loss of peat soils
- Settling caused by superimposed loads or other consolidation of subsurface material such as levee fills

Subsidence caused by the first mechanism is widespread in the Delta and affects the surface elevation of the whole island, especially areas that are actively cultivated. It can affect levee stability if it occurs close to the levees within the so-called "zone of influence" often estimated to be approximately 300 feet. Within this zone, subsidence has the effect of increasing the levee height and thereby increasing the water load (on the other side of the levee) that must be resisted. The reduction of soil weight and the steepening of the seepage gradient from the channel outside the levee will have some adverse effect on levee stability. However, often the peat soils in much of this zone are capped with a "toe berm" of inorganic material that stabilizes the levee and also prevents the oxidation from occurring.

The other large effect of peat oxidation is to increase the volume of floodwater that will flow onto the island if the levee breaches. The island has more "accommodation space" and a breach during the dry season would draw in a larger volume of saline water.

From the DRMS analysis of risks in future years (URS/JBA, 2008, Section 14), the following was the assessment for oxidation or other loss of peat soils:

> "The ground surface elevations in areas of the Delta-Suisun that have organic (peat) soils are expected to continue subsiding if current management practices are not altered. The DRMS analysis of subsidence has provided an analysis of the rates and amounts of subsidence both historically and projected into the future (see the Subsidence TM [URS/JBA 2007d]).
>
> "Subsidence rates are expected to decrease as the organic content percentage of the soil decreases and ultimately cease when the organic-rich layer is depleted. The duration of subsidence is dependent on the presence and thickness of the peat and organic deposits which are highly variable across the Delta (see the Subsidence TM [USR/JBA 2007d]). These effects largely counterbalance each other and the nominal subsidence for typical central Delta histosol is expected to be relatively constant at about 2.2 centimeters (cm) (0.9 inch) per year, until the organic content is largely depleted. An uncertainty band on this subsidence rate of +40 percent and -30 percent is stated. Subsidence rates in Suisun Marsh are expected to be much lower, because of a different management of the Suisun Marsh.
>
> "The medium expectation for future subsidence for the Delta and Suisun area with highly organic soils in terms of decreases in surface elevation and cumulative area-wide increases in accommodation space relative to 2005 sea level are:
>
> - For 2050: Up to 3 feet of subsidence and about a 25 percent increase of accommodation space
> - For 2100: Up to 8 feet of subsidence and about a 50 percent increase of accommodation space

- For 2200: Up to 17 feet of subsidence (accommodation space not estimated)

> "Note that these estimates of accommodation space increases are based only on progression of subsidence. Additional accommodation space increases will result due to any increases in mean sea level."

The second type of subsidence, settling due to superimposed loads or other subsurface consolidation, is a concern for the vast majority of Delta levees. The levees themselves are the superimposed load. They cause settling that must be minimized by careful, staged construction of levee improvements. Then, the settling that does occur must be mitigated by future levee repairs to restore the design levee height and cross section.

Either of these types of subsidence, peat oxidation or settling, can increase levee vulnerability if it is not adequately addressed by an aggressive, reliably funded maintenance program.

Sea Level Rise

The contribution that sea level rise will make to future Delta levee risks is significant and uncertain. The fact that the Fourth Assessment by the IPCC was heavily criticized because it did not adequately address the potential contributions of ice sheet melting in Greenland and Antarctica has added some confusion to the topic.

The CALFED Independent Science Board (ISB) reviewed and assessed the available science and provided a memo for use by Delta planning efforts such as Delta Vision. The ISB set forth their opinion on an approach for accommodating likely amounts and the uncertainty in sea level rise (CALFED, 2007; bullet format added):

> "The board recommends that planning efforts use three approaches to incorporate sea level rise uncertainty.
>
> - "First, given the inability of current physical models to accurately simulate historic and future sea level rise, until future model refinements are available, it is prudent to use existing empirically-based models for short to medium planning purposes. The most recent empirical models project a mid-range rise this century of 70–100 cm (28–39 in.) with a full range of variability of 50–140 cm (20-55 in.). It is important to acknowledge that these empirical models do not include dynamical instability of ice sheets and likely underestimate long term sea level rise.
> - "Second, we recommend adopting a concept that the scientific and engineering community has been advocating for flood management for some time. This involves developing a system that can not only withstand a design sea level rise, but also minimizes damages and loss of life for low probability events or unforeseen circumstances that exceed design standards.
> - "Finally, the board recommends the specific incorporation of the potential for significantly higher-than-expected sea level rise rates into long term infrastructure planning and design. In this way, options that can be efficiently adapted to the potential for significantly higher sea level rise over the next century will be favored over those that use 'fixed' targets for design. After all, the current debates over uncertainty in sea level rise are less about how much rise is going to occur and more about when it is going to occur."

Regarding the observation in their first point, that the above numbers do not include the sea level rise contribution of dynamical instability of ice sheets, the board stated:

"… dynamical instability of ice sheets will likely contribute significantly to future sea level rise, with the potential for very rapid increases of up to a meter (39.4 in.) by 2100 from ice sheets alone." Thus, to respond fully to the ISB recommendations, long-term infrastructure planning would need to consider sea level rise of up to 240 cm (7.9 ft) for 2100 and should include adaptive strategies to accommodate even more long term sea level rise.

The good news about sea level rise relative to Delta levees is the following:

- Sea levels rise is beginning slowly, presently estimated since 1990 at approximately 3.5 mm/yr (0.14 in/yr or 1.4 inches in 10 years) (CALFED, 2007).
- It takes time to accumulate, and this provides opportunity for mitigation and adaptation.
- Research on the topic is intensive and will likely provide significantly improved estimates in the next 5 to 20 years.
- Delta levees can be raised in stages to combat sea level rise as it actually develops, although this will be expensive to simply maintain the current level of protection.

Indeed, to accommodate sea level rise and subsidence Delta levees must be raised in stages. Their foundations cannot support large increases in loading applied all at one time. Thus, even a raise for 90 cm of sea level rise will usually need to be done in stages.

The other important consideration relative to sea level rise is the effect it has in increasing accommodation space. Each foot of sea level rise will mean that an additional foot of volume (on top of the previously existing volume) will exist in the island and that both those volumes need to be filled with floodwater if a breach occurs. Thus, the amount of saline water that will be drawn in from the Bay will increase accordingly, and this may mean a substantial increase in adverse consequences.

Floods: Future Risk with Climate Change

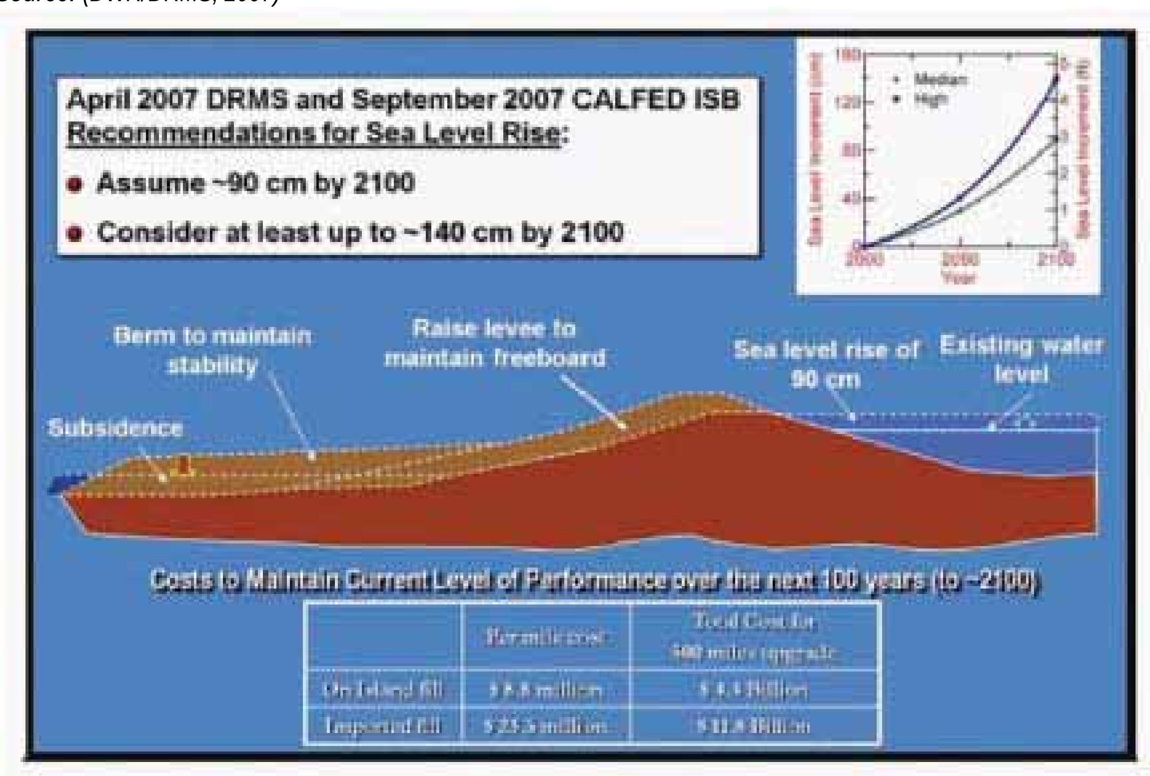
Estimating future flood risks used to be easier. It was assumed that the likelihood of a given sized flood would be the same in 50 or 100 years as it is today, and that past historical flood frequencies could be used to predict the future. So estimation of flood risks in future years could concentrate on analyzing how consequences of floods might change due to population growth, land use changes, and economic development. With climate change, the analysis must now be different. It is expected that with warming, less precipitation will fall in the Sierra as snow and more will fall as rain. There are some indications that the amounts of precipitation and intensities of winter storms will also change. Taking account of these changes in a quantitative way is a new area of hydrology and useful (credible) methods of analysis are only beginning to be developed. Thus, most studies have only given the qualitative description provided in the earlier portion of this paragraph.

The DRMS Climate Change Team (URS/JBA, 2008a) was able to obtain down-scaled results from four different Intergovernmental Panel on Climate Change (IPCC) scenario simulations. The results obtained were of daily, unimpaired runoff at key sites tributary to the Delta prepared by Professor Ed Maurer. The four scenario/models were those used by the Governor's Climate Action Team (CAT) in their analyses for their 2005/2006 report on California Climate Change (Cayan et al., 2006). The simulations were for two different emission scenarios (a2 and b1) as modeled by two different teams (National Center for Atmospheric Research or NCAR and Geophysical Fluids Dynamics Laboratory or GFDL). The simulations provided daily, unimpaired flows for 150 years (1950 to 2100) at some 20 stream gaging stations tributary to the Delta. These simulation results were analyzed by the DRMS Flood Hazard Team (URS/JBA, 2008b) to quantify the trends in frequency and size of major floods. Each simulation indicates increasing frequencies of the 7-day unimpaired Delta inflow that represents the year 2000 1 percent annual chance flood event (the 100-year flood). The ranges in frequency increases reported are (URS/JBA, 2008, Section 14):

- For 2050: Frequency increases of the present 1 percent annual chance flood are between 40 percent and 500 percent
- For 2100: Frequency increases of the present 1 percent annual chance flood are between 130 percent and 1,140 percent.

This means that in 2050, the present 100-year flood is expected to become something between a 17- and 70-year flood. In 2100, the present 100-year flood would become something between an 8-year flood and a 44-year flood.

Figure 5-16
Projected Costs to Maintain Current Level of Performance Due to Future Sea Level Rises and Land Subsidence
Source: (DWR/DRMS, 2007)



Another way to look at this result is to consider how much larger the peak flow of the future 1 percent annual chance flood might become. Based on the results provided by the DRMS Flood Hazard Team, the ratios to year 2000 peak inflows showing the increases in future peak 7-day Delta inflow are indicated for the respective climate scenario/model combinations in Table 5-4.

These calculations give only an initial indication of how Delta flood flows may change in future years. These ratios do not include any analysis of how flood flows are or will be attenuated by upstream storage reservoirs or by spilling into adjacent floodplains. But they seem to indicate that significantly larger runoff should be expected in flood events.

Table 5-4
Peak 7-Day Delta Inflow Flood Ratios with Climate Change Annual 1 Percent Chance Flood (100-Year Flood)

Climate Scenario	Year 2050 Ratio to 2000 Flow	Year 2100 Ratio to 2000 Flow
SRES b1-gfdl	1.2	1.4
SRES b1-ncar	2.2	3.5
SRES a2-gfdl	1.4	1.7
SRES a2-ncar	1.1	1.7

Source: URS/JBA, 2008b

A recent paper by Das et al. (2010) reports a more sophisticated analysis and confirms the direction and the significance of these expected changes. They summarize as follows:

> Analyses of future projections of flooding reveal that there is a general tendency toward the increase in the magnitude of three-day flood events. Specifically, by the end of the 21st Century, all of the projections contain larger floods for both the moderate elevation Northern Sierra Nevada (NSN) watershed and for the high elevation Southern Sierra Nevada (SSN) watershed, even for GCM simulations that project 8–15% decline of overall precipitation. The increases in flood magnitude are statistically significant (at p = 0.01 level) for all the three GCMs for the period 2051–2099 …. By the end of the 21st Century, the magnitudes of the largest floods increase to 110 to 150% of historical magnitudes.

Substantial work remains to extend these analyses to all Delta tributaries, but the work to date indicates that the results of those studies are badly needed for future planning efforts.

Other relevant analyses, including 112 downscaled simulations using a wider variety of global climate models and scenarios, are archived through the joint efforts of Lawrence Livermore National Laboratory, Bureau of Reclamation, Santa Clara University, and Climate Central (LLNL, 2010). Apparently, these results have not yet been analyzed with routing models, but when they are, a more robust conclusion should result (Duffy, 2010).

In the DRMS analysis, this assessment of future increases in flood frequencies was applied through a conceptual model of causation, resulting in the following points:

- Future increases in flood frequencies for given inflow magnitudes will translate into comparable increases in frequencies of flood-caused levee failures.
- Increased sea level will increase the hydrostatic load on the levee, the seepage gradient within the levee, the possibility of overtopping the levee and, thus, the conditional probability of a flood failure, even if the levee is raised to maintain freeboard and cross section geometry.
- Increased subsidence will also increase the hydrostatic loading and seepage gradients for at least some sections of levees and will increase levee vulnerability to flood failure in those cases.
- Thus, a given flood inflow will occur more frequently and result in an increased number of levee failures and will likely flood additional islands.
- More levee failures and flooded islands will require longer repair periods and more repair effort (cost).
- Increased sea level and the progression of subsidence together with more islands flooded will create more accommodation space that needs to be filled with water. This will mean additional pump-out costs. Salinity intrusion into the Delta is not expected to be an immediate occurrence

during inflow flood events. However, if the repair period is prolonged into the dry season for very large events, salinity could develop as a problem due to intrusion with tidal exchange. If so, it will require additional water for flushing.

In summary, no relationship within the conceptual model suggests an improved outcome for an intermediate variable that is important to levee risks related to inflow floods. All the intermediate variables will escalate in the direction of increasing risk under the changes expected for future flood events.

Earthquakes: Future Risk

DRMS considered how future risks from Delta levee failures due to seismic events might change. Results are reported in the Phase 1 Risk Analysis Report, Section 14 (URS/JBA, 2008). With respect to future frequency of seismic activity, the following was stated:

> "The time-dependent hazard curves developed as part of the probabilistic seismic hazard analysis (see the Seismology TM [URS/JBA 2007a]) were used to assess the increasing probability of ground motions for the future years 2050, 2100, and 2200. The peak ground acceleration (PGA) was used as a gauge for estimated percent increase in future earthquake hazards. The expected increases in frequency of a 0.20g PGA event are given below as percentages of the 2005 (base year) frequency:
>
> - For 2050: Frequency increases by 10 percent
> - For 2100: Frequency increases by 20 percent
> - For 2200: Frequency increases by 40 percent

The assessment of the future seismic hazard is based on the assumption that a major seismic event does not occur on one of the major Bay Area faults between now and the future evaluation years (2050, 2100, and 2200). As a result, tectonic strains are not released. Instead, they keep building up, thus increasing the probability of occurrence of future earthquakes. The Delta levees themselves were assumed to be raised to keep up with sea level, but their characteristics (geometric shape and freeboard) were assumed to stay constant and the levees were assumed to have an adequate maintenance program. However, several exogenous factors (in addition to more frequent earthquakes) would act on the levees resulting in an overall increase in both the likelihood of failure and the consequences. The DRMS analysis through a conceptual model of causation was reported as follows (URS/JBA, 2008, Section 14):

- Future increases in the frequency of seismic events (increasing probability of occurrence) for given earthquake magnitudes on a given fault will translate into comparable increases in frequencies of seismic levee failures.
- Increased sea level will increase the hydrostatic load on the levee, the seepage gradient within the levee, and the conditional probability of a seismic failure.
- Increased subsidence will also increase the hydrostatic loading and seepage gradients for at least some sections of levees (if the subsidence is within the "zone of influence" for the levee) and will increase levee vulnerability to seismic failure in those cases.
- Thus, a given seismic event will occur more frequently and result in an increased number of levee failures and will likely flood additional islands.
- More levee failures and flooded islands will require longer repair periods and more repair effort (cost).

- Increased sea level and the progression of subsidence together with more islands flooded will create more accommodation space to be filled with water when a breach occurs. This will mean additional salinity intrusion into the Delta and will require additional time and water for flushing.
- Disruptions for both in-Delta water users and exports will be lengthened and more severe.

In summary, no relationship within the conceptual model of Delta levee performance for earthquakes suggests an improved outcome for an intermediate variable that is important to future levee risks. All the intermediate variables will escalate in the direction of increasing risk under the changes expected for future seismic events.

Future Consequences

The second element of the risk equation, the consequences of inundation, is also expected to increase future risks for both floods and earthquakes. DRMS (URS/JBA, 2008, Section 14) assessed the changes in Delta area population, land use, and economic activity. The expected changes of regional and statewide population and activity that are affected by the Delta were also assessed. The available data indicate that all these factors are undergoing steady, substantial growth. Key points from applying the DRMS conceptual model and focusing on consequences are:

- **Public health and safety.** The risk consequences for public health and safety (endangerment of people's lives) must be expected to increase in future years because there will be more frequent events involving the flooding of more islands and, with increases in Delta population and urbanization, more people will be exposed.
- **In-Delta damage.** The consequential damages to in-Delta infrastructure, property and economic activity and the cost of levee repairs are expected to increase in future years as a result of the increasing likelihood of the hazards and the decreasing reliability of the levees, as discussed above**.** More frequent flooding involving more islands and more salinity intrusion for longer durations can only mean that damage levels escalate. In addition, more people and higher levels of land use and economic activity will be exposed. This will further escalate in-Delta damages.
- **Statewide economic impacts.** The consequences to California's economy will certainly increase in future years. The above-described in-Delta damage escalation will be part of the increasing impact to the state. However, with less water supply yield and more frequent Delta levee breach events involving more islands and more salinity intrusion, the disruption of Delta water exports will be more severe. Even if target amounts of water export remain unchanged, more people and higher values of economic activity will be exposed to disruptions of their water supply. Thus, the consequences to the California economy will be driven higher by multiple forces.
- **Ecosystem impacts.** More frequent levee breach events involving more islands with more salinity intrusion for longer duration will, in the short term, increase the adverse impacts (e.g., entrainment, turbidity, loss of water quality, pump out, loss of habitat, and increased predation) as well as offer opportunities (e.g., new habitat or temporary interruption of water export). A few species may see beneficial impacts …. However, an increased threat to sensitive species must be expected.

Especially in the Secondary Zone of the Delta, the factors that increase consequences are expected to increase substantially. Land developments in the areas near the principal cities have been progressing dramatically, at least before the recent recession. This is accompanied by increases in exposed population, economic activity, infrastructure and property. These factors, to the extent that projections are available, are seen to be increasing by amounts in the vicinity of 100 percent, usually in the 2030 to 2050 timeframe (URS/JBA, 2008). The result is that overall consequences of island failures and inundation are likely to increase dramatically, since the increased likelihood of flooding and the increases in consequence factors compound. Thus, the overall risks from Delta levee failures and island inundation are expected to increase substantially in future years.

Aggregated Future Risks

The DRMS analysis of risks in future years did not produce a quantitative aggregation of future risks. Instead it assembled figures that portray the ratios by which risk factors are expected to increase by 2050 and 2100. These risk factor ratios are illustrated in Figure 5-17 for 2050 and Figure 5-18 for 2100. Since the risk factor increases compound when calculating total future risk, the figures do not really do justice in portraying the total increase in risks expected. For example, the 2050 ratios for "normal" (sunny day, high tide) failures are 1.1, 1.2, and 1.2. Compounded, these may become 1.6, but the compounding is not necessarily that simple. Finally, a mechanism for aggregating the three types of levee breach events is not easily defined. Assuming levees are raised to respond to sea level rise and subsidence, it is clear, however, that the risk factors that have the major effects in increasing future risks are:

- The increased frequency (or size) of floods with climate change.
- The increased population and economic activity in the areas affected by levee breaches.
- The increased "accommodation space" and the potential for increased saline water intrusion in earthquake-caused levee breach events.

As a measure of the overall rise in risk for the three types of levee breach events that were found in the DRMS analysis for 2050 and 2100, the medium estimates of increases in frequencies of failures are given in Table 5-5 and the increases in expected economic losses from failures are given in Table 5-6.

Table 5-5
Medium Expected Increases in Frequencies of Failures Over 2005

Type of Breach Event	2050 Increase	2100 Increase
Seismic	35%	93%
Flood	261%	798%
Normal (sunny-day, high-tide)	23%	61%

From URS/JBA, 2008, Tables 14-16, 14-17, and 14-18

Table 5-6
Medium Expected Increases in Economic Losses Over 2005

Type of Breach Event	2050 Increase	2100 Increase
Seismic	202%	500%
Flood	723%	>800%
Normal (sunny-day, high-tide)	174%	400%

From URS/JBA, 2008, Tables 14-21, 14-22, and 14-23

Note that these are percentage increases. For a 200 percent increase, the total value of economic losses would be three times the base case; thus a $100 million loss would escalate to a $300 million loss.

Figure 5-17
Risk Factor Ratios for 2050
Source: URS/JBA, 2008

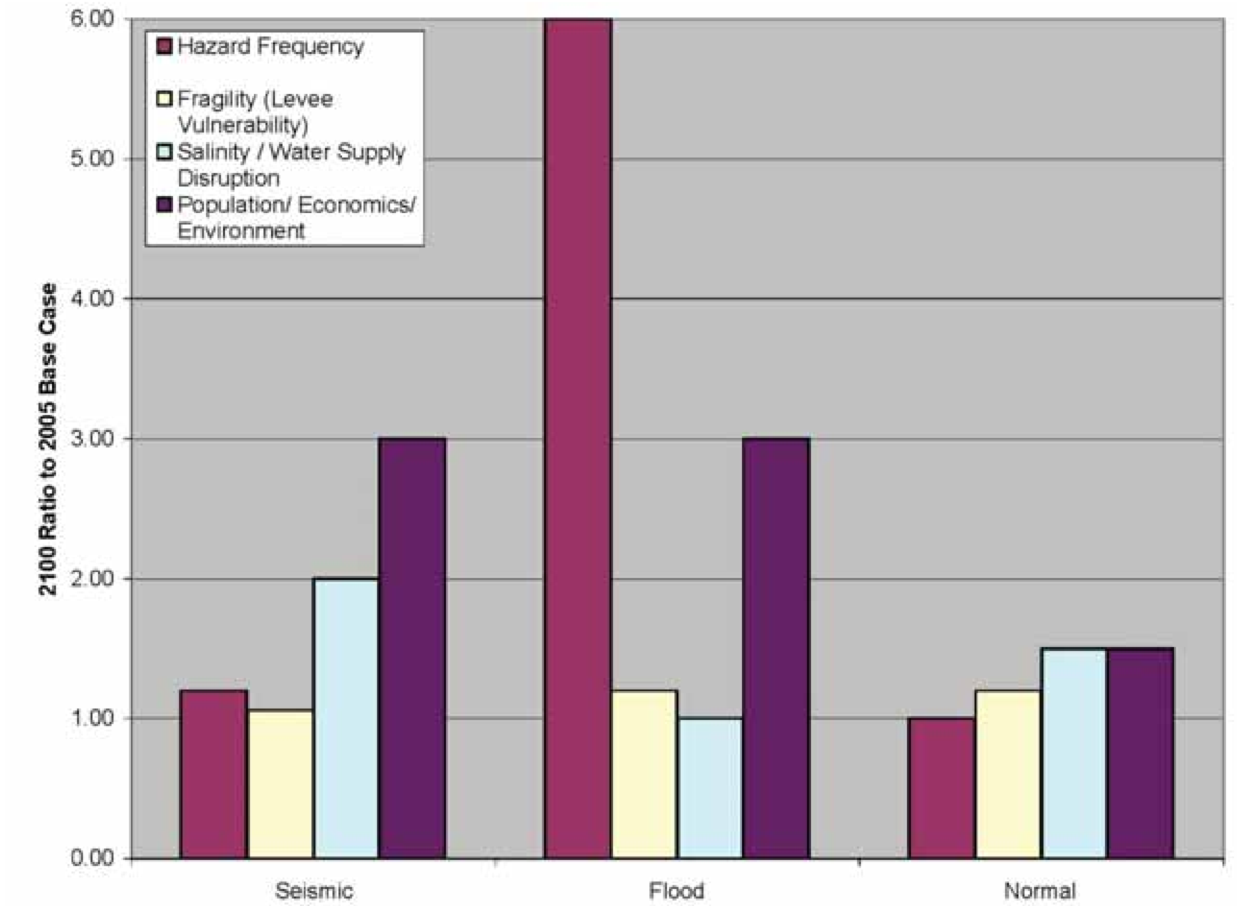
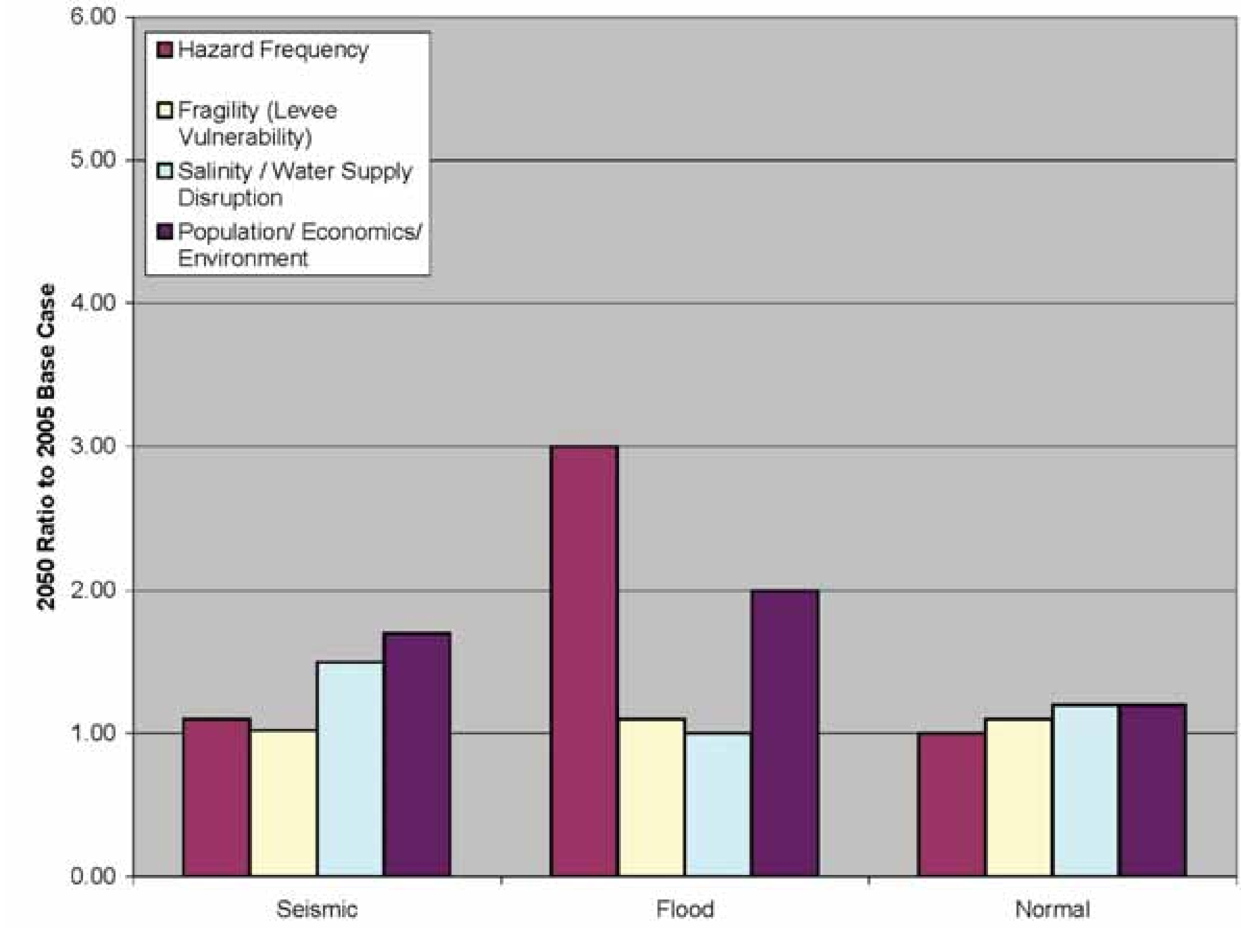


Figure 5-18
Risk Factor Ratios for 2100
Source: URS/JBA, 2008



Section 6
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